University of Nebraska Lincoln
Institute of Agriculture and Natural Resources

Center for Agricultural
Meteorology and Climatology
L. W. Chase Hall
Lincoln, NE 68583-0728
(402) 472-3679

September 20, 1983

Mr. Melvin Keener
Standard Oil Company
3092 Broadway
Cleveland, Ohio 44115

Dear Melvin:

Thank you for your timely offer. Enclosed is a copy of my resume, list of publications and transcript. The job description is interesting. The objective of developing "a better corn plant" is challenging. My educational background (M.S. and Ph.D.) has been primarily with moisture stress responses of some commercially available corn hybrids. I have also acquired an associate degree in electronics, which has been helpful as I have had the opportunity to operate and occasionally perform limited repair on a variety of research instrumentation. The greatest benefit of this degree has been in the area of understanding what an instrument is really doing.

The instrumentation I have operated include the LI-Cor 1600 diffusion porometer, air and leaf thermocouples, various infared thermometers, the Barnes Multiband Radiometer (simulates the thematic mapper) the Exotech 100 (simulates the Landsat MSS instrument), net radiometers, anemometers, pressure bombs and neutron probes.

My computer experience has been centered primarily on CMS and the SAS language. My fortran is fairly weak, but I have had some experience with it. SAS is my preferred statistical analysis tool, however. I have used SAS extensively in the summary and analysis of the voluminous multivariate data which is generated in remote sensing studies.

My ideal job-scenario would be for me to start at Standard around the first of March. (This would allow me sufficient time to wrap up all the loose ends around here). Then, work 12-14 months on this project. By this time, Blaine's China project would be in full-swing. Blaine has indicated the possibility that I could fill that job here, be granted a leave of absence and then return around March of 1984.

Obviously, the ideal is not always practical, but is a good spring board for further discussions.

Sincerely,

Bronson Gardner

Bronson Gardner

BG:nkb
Encl.

University of
Nebraska
Lincoln
Institute of Agriculture and Natural Resources

Center for Agricultural
Meteorology and Climatology
L. W. Chase Hall
Lincoln, NE 68583-0728
(402) 472-3679

November 4, 1983

Dr. Melvin Kenner
3292 Broadway
Cleveland, Ohio 44115

Dear Mel:

Thank you for the opportunity to visit your site. The projects are interesting. Blaine has indicated an interest in being involved in them. My wife also is interested in the opportunities in Cleveland. Enclosed is my expense voucher and receipts. Thanks again for the interview opportunity.

Sincerely,

Bronson Gardner

Bronson Gardner

BG:rls
Encls

NAME AND ADDRESS MUST BE COMPLETE
SHOW POSTAL ZONE (NO ABBREVIATIONS)

REIMBURSABLE EXPENSE REPORT

Receipts MUST be attached for ANY EXPENDITURE of $25.00 or more and for ALL LODGING

NAME	COMPANY	DIVISION	DEPARTMENT	☐ ISSUE CHECK $
BRONSON GARDNER	UNIV. of Nebraska			
STREET	**SOCIAL SECURITY NO.**	**BUSINESS PURPOSE OF TRAVEL OR ENTERTAINMENT**		☐ CREDIT ADVANCE $
2259 Y St #210	554-78-8209	INTERVIEWING FOR POST-DOCTORAL		
CITY ZONE			NUMBER OF DAYS ON BUSINESS	☐ CASH RETURNED $
LINCOLN, Nebraska 68503				

DATE	LOCATION (CITY, ENROUTE, ETC.)	LODGING (ATTACH RECEIPTS)	MEALS (YOUR OWN)	** MEALS (OTHER THAN YOUR OWN)	TRANSPORTATION AIR / RAIL / BUS	TAXI / BUS TOLLS	PHONE WIRE	** ENTERTAINMENT	OTHER EXPENSES (IF AUTO SHOW VEHICLE NUMBER) ITEM	OTHER EXPENSES AMOUNT	TOTAL AMOUNT	OPERATIONS CHARGEABLE
NOV. 83	Cleveland (from Lincoln)	61.88	- -	- -	230 00	5 50					297.38	
2 NOV 83	Cleveland (to Lincoln)	- -	3 00	- -	- -	5 50					8.50	
	TOTAL	61.88	3.00		230 00	11 00					305.88	TOTAL EXPENSES

EXPLANATION (IF MORE SPACE IS NEEDED USE REVERSE SIDE)

TOTAL AMOUNT SPENT (INDICATE IN WRITING) Three ~~Five~~ Hundred and Five and 88/100 — 305. 88 CENTS

EMPLOYEE'S SIGNATURE

Bronson Gardner

DATE

NOTE: Show proper Expense Code and Unit No. (Below)

NOTE ↓ SHOW UNIT NO

A. F. E	FUN.	ACCOUNT	STATE DIV.	DEBIT	CREDIT

VERIFIED BY

APPROVAL

** DESCRIBE IN DETAIL EACH EXPENDITURE. SHOW: PLACE—TYPE OF ENTERTAINMENT—BUSINESS PURPOSE—NAME OF INDIVIDUALS AND BUSINESS RELATIONSHIP WHERE ENTERTAINMENT DIRECTLY PRECEDES OR FOLLOWS A SUBSTANTIAL BUSINESS DISCUSSION, SHOW: DATE—DURATION—PLACE AND NATURE OF BUSINESS DISCUSSION.

CLV—223-G

305	RATE	6/02	ARV	C/O	GTD/6PM
[illegible] 3662 BROADWAY CLEVELAND OH 44115	[illegible] NCD [illegible]	ARV 4/1 CLERK AC	[illegible] CHARGE TO [illegible] PH: (216) 271-4101 EX 12/83 RESERVATION NUMBER		
SGL- 1 35.00 AG:			A: 1 C: 0	REMARKS: C/ CORP RATE ONE [illegible]	

NO. 087936	MEMO	DESCRIPTION	CHARGE/CREDIT	BALANCE
1	GAMBLE	ROOM	3.00	
2		RTAX	5.00	
3		LDIST	2.36	
4		TS 565A11/01 30 BAL		64.44
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7		BALNC		64.44
8		TR CR	2.36-	
9		G1054A11/02 30 BAL		61.86
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13		BALNC		61.86
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BILLING SIGNATURE

BILLING ADDRESS

STREET

CITY STATE ZIP

Marriott
CLEVELAND MARRIOTT INN EAST
3663 PARK EAST DR.
I-271 AT CHAGRIN BLVD.
BEACHWOOD, OHIO 44122

See below for Airline Form, Serial Number

PASSENGER TICKET AND BAGGAGE CHECK ISSUED BY — SUBJECT TO CONDITIONS CONTAINED IN THIS TICKET

CONJUNCTION TICKET(S)

UNITED AIRLINES

ATC PASSENGER COUPON

DATE OF ISSUE: 15OCT83

ORIGIN: LINCOLN

DESTINATION: LINCOLN

VIA VAN BLOOH

PSGR CPN

PASSENGER NAME: GARDNER/BRONSON — NOT TRANSFERABLE

ISSUED IN EXCHANGE FOR

LINCOLN NE

2891591 2E /AP

X/O	FROM / TO — NOT GOOD FOR PASSAGE	CARRIER	FLIGHT	CLASS	DATE	TIME	STATUS	FARE BASIS/TKT. DESIGNATOR	NOT VALID BEFORE	NOT VALID AFTER	ALLOW
	LINCOLN	UA	3140		1NOV	219A	OK	Q			
X	CHICAGO/OHARE	UA	4220		1NOV	1134A	OK	Q			
O	CLEVELAND	UA	7210		2NOV	535P	OK	Q			
X	CHICAGO/OHARE	UA	2530		2NOV	659P	OK	Q			
	LINCOLN										

BAGGAGE CHECKED / UNCHECKED — PCS. / WT. / UNCHECKED / PCS. / WT. / UNCHECKED / PCS. / WT. / UNCHECKED / PCS. / WT.

FARE: 212.97

FARE CALCULATION: 1NOV LNK UA -XORD Q UA CLE 115.00Q UA -XORD Q UA LNK 115.0

EQUIV. FARE PD: $230.00

TAX: 17.03

TOTAL: 230.00

FORM OF PAYMENT: CHECK

TOUR CODE

A/L-AGT. INFO.: 0162/ 46454

CONTROL NO.: 2800566865

CPN. | AIRLINE CODE | FORM | SERIAL NUMBER | CK: 016 7513850809 3 □

ORIGINAL ISSUE: 0162

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NAME AND ADDRESS MUST BE COMPLETE
SHOW POSTAL ZONE (NO ABBREVIATIONS)

REIMBURSABLE EXPENSE REPORT

Receipts MUST be attached for ANY EXPENDITURE of $25.00 or more and for ALL LODGING

NAME	COMPANY	DIVISION	DEPARTMENT	
Bronson Gardner	Univ. of Nebraska		Agric. Meteor.	☐ ISSUE CHECK $
STREET	**SOCIAL SECURITY NO.**	**BUSINESS PURPOSE OF TRAVEL OR ENTERTAINMENT**		☐ CREDIT ADVANCE $
2259 Y St. Apt 210	554-78-8209	Design 1984 Field Experiment		
CITY ZONE			NUMBER OF DAYS ON BUSINESS 2	☐ CASH RETURNED $

DATE	LOCATION (CITY, ENROUTE, ETC.)	LODGING (ATTACH RECEIPTS)	MEALS (YOUR OWN)	** MEALS (OTHER THAN YOUR OWN)	TRANS. PORTATION AIR RAIL BUS	TAXI BUS TOLLS	PHONE WIRE	** ENTER-TAINMENT	OTHER EXPENSES (IF AUTO SHOW VEHICLE NUMBER) ITEM	OTHER EXPENSES AMOUNT	TOTAL AMOUNT	OPERATIONS CHARGEABLE
8 JAN '84	Lincoln Neb - Cleveland, Ohio	79 88	15 50		250 00	7 00					352 38	
19 Jan	cleveland, Ohio	79 88	9 00						gas	8 00	96 88	
20 Jan	cleveland, Ohio	— —	5 50						gas	7 65	13 15	
21 Jan	cleveland Ohio - Lincoln, Neb	— —	— —			7 00			CAR Rental 3 Days	160 05	167 05	
	TOTAL	159 76	30 00		250 00	14 00				175 70	629 46	TOTAL EXPENSES

EXPLANATION: (IF MORE SPACE IS NEEDED USE REVERSE SIDE)

(INDICATE IN WRITING)

TOTAL AMOUNT SPENT Six Hundred Twenty-Nine and 46/100 $ 629.46 CENTS

EMPLOYEE'S SIGNATURE

Bronson Gardner

DATE

NOTE ↓ SHOW UNIT NO

NOTE: Show proper Expense Code and Unit No. (Below)

A. F. E.	FUN.	ACCOUNT	STATE DIV.	DEBIT	CREDIT

VERIFIED BY

APPROVAL

** DESCRIBE IN DETAIL EACH EXPENDITURE. SHOW, PLACE—TYPE OF ENTERTAINMENT—BUSINESS PURPOSE—NAME OF INDIVIDUALS AND BUSINESS RELATIONSHIP.
WHERE ENTERTAINMENT DIRECTLY PRECEDES OR FOLLOWS A SUBSTANTIAL BUSINESS DISCUSSION, SHOW, DATE—DURATION—PLACE AND NATURE OF BUSINESS DISCUSSION.

CLV—223-G

CLV-81

THE STANDARD OIL COMPANY
OFFICE CORRESPONDENCE

March 26, 1984

APR 2 2 198
J.D. DU...

M. E. Keener
Broadway Lab

Re: Remote Sensing

I thought that Bronson Gardner did an outstanding job of presenting some of the possibilities of remote sensing and their effect on Ag Products Division and other parts of the company.

According to our agreement, in the near future we will obtain for APD data on the crops planted in a 20 mile radius of Roseanna, Ohio retail outlet of APD. Please let me know when this information is pulled together so that we can discuss it with Tom Rooney and David Hill.

On an intermediate term goal in this project, I'd like to have you identify what would be necessary to show that remote sensings can be used to control irrigation in growing corn and an additional crop such as wheat or soybeans. I would like to be able to do an analysis of the benefits that could be derived from remote sensing during this growing season. As we discussed, I would like to know what is required to do such a comparative test. Once this has been determined, we can discuss how we could accomplish this comparative test.

On a longer term basis, it appears that some of this information would be extremely useful in identifying oil and mineral deposits and increase our probability of finding these deposits. I agree it would be useful to hear a presentation from the gentleman from the Jet Propulsion Laboratory. I think we should schedule a date for this presentation and invite all interested parties to hear what is possible and to gain a better understanding of how this technology could fit into their commercial interests.

I personally believe that this remote sensing offers a lot of commercial possibilities and am extremely pleased that this opportunity was brought to our attention.

Herbert D. Knudsen

HDK/ej
0203Q

cc: J. D. Burrington
D. S. Hill
S. C. Price
R. A. Rightmire
T. M. Rooney
Bronson Gardner

THE STANDARD OIL COMPANY

OFFICE CORRESPONDENCE

March 30, 1984

To: Herbert Knudsen

From: Bronson Gardner

Re: Remote Sensing

Here is some preliminary information concerning the intermediate project of scheduling irrigation for corn and other crops. Also included is some additional information on the use of Landsat data to obtain cropping patterns for the Roseanna (Waynesville) outlet of APD.

In the near future I will contact Dr. Barrett Rock of the Jet Propulsion LAB to schedule a presentation on the use of Remote Sensing for identifying oil and mineral deposits.

Bronson Gardner

BG:pl

Enclosure

cc: J. D. Burrington
D. S. Hill
S. C. Price
M. E. Keener
T. M. Rooney

MATERIALS NEEDED FOR AN INFRARED THERMOMETER CENTER PIVOT IRRIGATION SCHEDULING FOR CORN

1. 2 center pivots - one as a control and one for experimenting. The control will be treated conventionally. The other will be irrigation scheduled with an infrared thermometer. All other cultural practices would be normal.

2. 1 neutron probe for measuring soil water contents at several sites in each pivot.

3. Several neutron tubes (aluminum pipes about 2" in diameter) and use of a Giddings probe truck for installing the neutron tubes.

4. 1 infrared thermometer for measuring canopy temperature.

5. Several rain gauges for measuring irrigation and rainfall.

6. Grain yields from each pivot.

7. 1 weather station (windspeed, radiation, air temperature and humidity).

8. 1 worker (probably one-half time) to collect the data.

9. The pivot to be scheduled with the infrared thermometer must be turned on <u>whenever</u> the need is indicated. No delays.

NOTE: The experiment does not need to begin until full canopy cover (10-12 leaf stage)is reached. Both pivots will be treated conventionally until then.

<u>Other Crops</u>

This experiment can be repeated for other crops, such as soybeans or wheat. It should be cautioned, however, that this technology has not been extensively studied for crops other than corn (for irrigation scheduling purposes). Some data on soybeans is available however.

DETERMINING CROPPING PATTERNS IN AN APD AREA

One approach which can be used to determine the cropping patterns and acreages in a given area is to use historical data. For example, APD has an outlet in Waynesville, Ohio (called the Roseanna site). The Ohio Crop Reporting Service, in conjunction with the USDA, routinely publish such information for agricultural areas throughout the United States. (Table 1). Table 1 gives the user a feel for the agricultural production around the Roseanna site. It should be noted, however, that the 1983 data is not yet available. There is approximately a one year delay in obtaining this type of information. For many purposes, however, it may be adequate. It is readily available at a very low cost.

It should be noted that USDA statistics may contain significant errors on the county level, since their acreage estimates are geared for state and national production. County estimates are performed by each state. The basis for all these statistics are farmer surveys. The reliability of their surveys is also subject to question.

Remote Sensing offers another approach to this problem. Currently, the resolution on the Landsat satellite is adequate for detecting areas about one acre in size. A new satellite instrument has recently begun providing data which has the resolution to detect canals and roads. Historical data on the older satellite is available for several years, however.

Significant software has been developed (and is commercially available) for processing satellite data and classifying crops. The satellite approach could be used in areas where: a. USDA statistics are unavailable or not trusted, b. patterns in an area smaller than a county are desired. No research has been conducted on developing historical data for the cropping patterns on a specific farm. This study would be unique to SOHIO.

After a preliminary discussion with NASA and university experts, the following general outline can be given as to how we could acquire LANDSAT data to develop historic cropping patterns for a given farm (or larger area up to 100 miles X 100 miles):

1. Develop an "inhouse" image processing capability. According to Don Rundquist at the University of Nebraska, we probably have most of the needed hardware. The necessary software is commercially available. The basic problem is that a large segment of computer memory is required to process the data. This probably would require doing the processing during off-hours (night or weekends).

2. Acquire the satellite data for the specific area of interest. According to Dave Thompson at NASA, we would need at least 4 separate satellite overpasses for each crop season for each area to reliably estimate the cropping patterns. The cost of a single overflight data tape is $650.00. Thus, a maximum cost of $2600-$3000 per year per area can be expected. The cost may be significantly less than this if we accurately know the small areas for which an analysis is to be

conducted. A listing of all data available for the Waynesville area is being sent to us by NASA.

3. Another alternative is to conduct a pilot study (if we buy the data) at the University of Nebraska facility. Don Rundquist has indicated his willingness to help. There would be computer time to pay for, and there may be some additional charge for his time (he hasn't decided this point yet), as well as travel expenses. The approximate total cost for a pilot study for determining cropping patterns around Waynesville for a single year using the University of Nebraska facility cannot be determined at this time.

The cost for the data could be eliminated if we used a site in Nebraska, since they have already acquired a large satellite data base (for several years). Consequently, a specific site in Nebraska could be analyzed for several years worth of data. Don Rundquist should be consulted on the feasibility of this option.

TABLE 1

March 26, 1984

WARREN COUNTY, OHIO, AGRICULTURAL STATISTICS
OHIO CROP REPORTING SERVICE

Includes Waynesville
(39° 32' 11' N; 84° 5' W)

	Corn for grain			Soybeans		
Year	Acres	Bu./acre	Production	Acres	Bu./acre	Production
1973	29,300	80.8	2,367,900	38,800	23.1	896,700
1974	37,700	75.9	2,861,800	38,100	26.8	1,020,000
1975	33,200	90.6	3,007,000	36,600	32.2	1,180,100
1976	42,500	101.1	4,297,000	33,400	31.9	1,064,000
1977	48,700	96.7	4,709,300	40,600	31.4	1,276,000
1978	38,400	105.6	4,055,000	49,900	32.9	1,644,000
1979	35,400	108.8	3,850,000	60,200	32.1	1,930,000
1980	43,800	111.6	4,886,000	54,000	30.2	1,631,000
1981	45,400	93.2	4,233,000	43,000	32.7	1,407,000
1982	51,400	126.1	6,482,000	39,000	35.2	1,373,000
		Winter wheat			Oats	
1973	8,700	28.0	244,000	1,700	41.0	69,700
1974	10,100	32.8	331,300	800	40.0	32,000
1975	10,000	34.9	349,500	1,200	35.8	43,000
1976	10,100	34.0	343,600	1,100	37.4	41,200
1977	10,000	42.4	424,200	1,300	41.5	53,900
1978	5,700	37.5	214,000	900	47.9	43,100
1979	6,800	39.5	268,300	900	46.6	41,900
1980	4,900	44.9	220,000	1,300	49.0	63,700
1981	10,300	36.5	376,000	1,100	61.5	67,700
1982	8,500	42.9	365,000	900	63.3	57,000
		All hay				
		Ton/acre				
1973	16,900	2.0	33,800			
1974	14,800	1.8	26,600			
1975	13,800	2.2	30,800			
1976	13,500	1.9	25,000			
1977	15,400	2.1	32,000			
1978	12,600	2.3	29,000			
1979	11,200	2.1	23,000			
1980	12,200	2.3	27,800			
1981	11,000	3.0	33,000			
1982	12,200	3.2	39,000			

THE STANDARD OIL COMPANY

OFFICE CORRESPONDENCE

April 18, 1984

TO : D. Hill

FROM: B. Gardner

RE : Remote Sensing

The approximate cost of acquiring and processing aircraft thermal data for a ten (10) mile region (2 or 3 flights) is $20,000-$30,000. The major expense is the renting and operation of the airplane. It may not be necessary to use an airplane-mounted thermal scanner, however. The Eros Data Center has informed me that we can acquire a photographic image (29" x 29") of a data scene for $150 per channel. The area included is approximately 115 miles x 115 miles. Thus, on the photograph, 1/4 inches = 1 mile. With in-house "blow-ups" of an area of interest, we could thermally characterize an area at a low cost. The basic problem with thermal data from satellites is that it is acquired about 9:30 a.m. local time. Consequently, stress levels will not be fully developed by then. The information may still be useful, however. Water stress can show up in the morning if severe enough.

Another approach to acquiring thermal data would be to use a portable television thermal image. These devices are currently used for studying heat-losses in buildings. Their resolution is fairly coarse, but sufficient to detect relatively warm areas (1 or 2 degrees). A simple Polaroid picture of the T.V. image could be used by a salesman in discussing a farmer's field. The images could be acquired from anything which could elevate an observer 5-10 feet (at least) above the crop canopy (e.g. a ladder-truck). One ladder-truck with a T.V. imager could be used over a fairly large geographical region. With this approach, a farmer's fields could be analyzed area by area. Alternatively, the T.V. camera could also be put in a helicopter or airplane for large area coverage. This system would probably be the cheapest way to thermally characterize a farm. The utility of this system for irrigation scheduling has not been investigated but holds promise. If the system is sensitive enough, a farmer could simply look at a T.V. monitor, scan his field and decide whether or not to irrigate.

I have just become aware of another agricultural use of remote sensing technology. The USDA has found that protein content in grain is directly correlated with its spectral properties (after being crushed). They now have a simple (fast and cheap) analysis tool for accurately estimating protein content. Perhaps such an analysis could be provided as a service to those who purchase APD chemicals?

R. E. Darringer, president of the Telatemp Company has sent me a proposal for developing an infrared thermometer system for scheduling irrigation and/or determining the optimum time to apply fertilizer or other chemicals. If we decide to conduct an irrigation scheduling experiment, his company may be able to provide some essential hardware and/or expertise. Enclosed is a copy of his proposal.

Apparently, several oil companies are already using remote sensing information to aid in exploring for minerals, petroleum and gas deposits. For example, Dave Freeman, at the Sun-Oil Company (Dallas, Texas), carries radiometers to the field for measurements. I do not know for what purpose, but perhaps some of the geologists may have an inkling.

Barrett Rock, Jet Propulsion Laboratory specialist, says he is interested in being invited to explain the agricultural and geological data which he has been recently collecting with a new high-resolution, high data density sensor. He has indicated he would have time to do this around the 19th or 20th of June, the 2nd or 3rd of July or around the 20-27th of August. His phone number is (818) 354-6229.

BG:rih

Bronson Gardner

Enclosure

cc: J. D. Burrington
H. D. Knudsen
S. C. Price
M. E. Keener
T. M. Rooney

THE STANDARD OIL COMPANY
OFFICE CORRESPONDENCE

April 19, 1984

TO : H. Knudsen

FROM: B. Gardner ✓

RE : Irrigation Scheduling

I have just learned of a potentially important opportunity for testing our irrigation scheduling ideas. Two individuals, Larry Campbell and Fred Heppler have expressed interest in this idea. Larry is a farm manager for several large farms in the Mississippi delta. He has indicated a willingness to cooperate in a test program to schedule irrigation using an infrared thermometer. He may be contacted at:

Larry Campbell
P.O. Box 247
Earle, Arkansas 72331
Phone: (501) 792-8640

Fred Heppler is a friend of Larry. Fred owns 160 center pivots (110,000 acres) in Nebraska. Fred has told me he is very interested in this project and is anxious to cooperate. He can be contacted at:

Fred Heppler
Thunderbolt Farm
Star Route Box 9-A
Bartlett, Nebraska 68622
Phone: (402) 482-5236

Fred also has a high quality weather station available and has the capacity to electronically monitor activity at some of his pivots. He has indicated his biggest interest is not necessarily saving water (he feels he has done much along those lines with a conventional irrigation consultant). His interest is in more precisely determining when to irrigate. Canopy temperature measurements are ideal for this purpose.

If you determine we should be involved with Fred or Larry (or both), I will be pleased to assist in the development of this project.

BG:rih

Bronson Gardner

cc: S. C. Price
M. E. Keener
D. S. Hill
J. D. Burrington
T. M. Rooney

CLV-81

THE STANDARD OIL COMPANY
OFFICE CORRESPONDENCE

May 25, 1984

Memorandum

Nebraska Trip: May 13-20, 1984

Fred Hepler Irrigation Scheduling Experiment

I met with Fred Hepler to discuss the feasibility of using an infrared thermometer to schedule irrigations on a center pivot. Dr. Blaine Blad (from the University of Nebraska) also participated in the discussion.

Several points were clarified.

1. Fred is willing to work with us. The potential for improving his irrigation scheduling is there.

2. A contract is needed as soon as possible. The first measurements should be taken around the 15th-20th of June.

3. Two objectives for this technique were defined:

   a. Maximize crop rooting depth. This is done by mildly stressing the crop during vegetative growth, or by taking the crop to the edge of stress. Since the tasseling and pollination period are so critical to end-of-season grain yields, Fred will operate as normal during mid-season.

   b. Starting around the middle of the grain-fill period the second objective is to use the deep root system to efficiently mine the water beneath the pivot. Canopy temperatures will be measured daily throughout the season, even when Fred is irrigating normally.

4. The protocol can be somewhat different for objective 1 than 2. During early vegetative growth, the crop is small, exposing a significant amount of soil to the view of the infrared thermometer, unless individual plant temperatures are measured. This necessitates the measuring of canopy temperatures down the row by an observer. During objective 2, when the crop is at maximum height, canopy temperatures can be measured across a row while an observer stands on top of the center pivot, or carrying the instrument on a very tall pole.

5. This protocol suggests that the best procedure for an automatic system would be to have the infrared thermometer collect canopy temperatures along the rows. The system would therefore not be a t tached to the pivot, although it could still be used to control a pivot, a third objective identified by Fred.

Contact: Fred Hepler
Thunderbolt Farm
Star Route Box 9-A
Bartlett, Nebraska 68622
(402) 482-5236

He can also be contacted at home after 10:00 p.m. or around 4:00 a.m. at:

(402) 336-4899

The data collection procedure is:

1. Divide the pivot into a wet (most recently irrigated) and dry (longest time since irrigation). This is already routinely done by Fred.

2. Establish the mean and standard deviation of canopy temperature for the wet and dry side. Data must be collected only when the sun is unobscured. (See figure 1).

    a. measure canopy temperature for 15 minutes in the wet side (w_1)

    b. measure canopy temperatures for 15 minutes in the dry side (d_1)

    c. measure canopy temperatures for 15 minutes in the dry side (d_2)

    d. measure canopy temperatures for 15 minutes in the wet side (w_2)

    e. steps a-d can be repeated, if desired

3. Calculate the mean and standard deviation of d_1, d_2, w_1, and w_2

4. Compare d_1 with w_1 and d_2 with w_2 (also d_3 with w_3 and d_4 with w_4, if collected). Make a judgement concerning whether to irrigate.

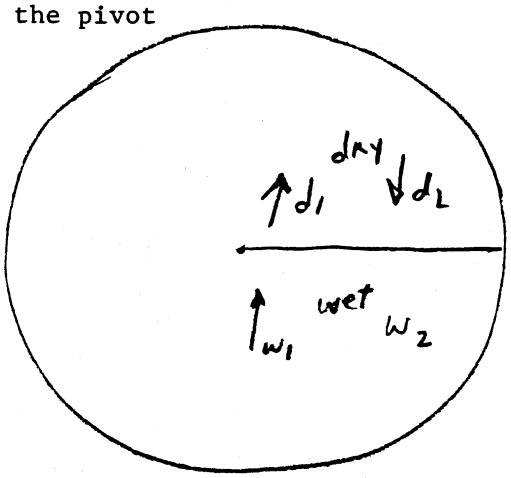
The physical collection of the data is:

a. when the crop is short, the observer walks along a row, pointing the instrument at individual plants. A hand held tape recorder is used to record the numbers

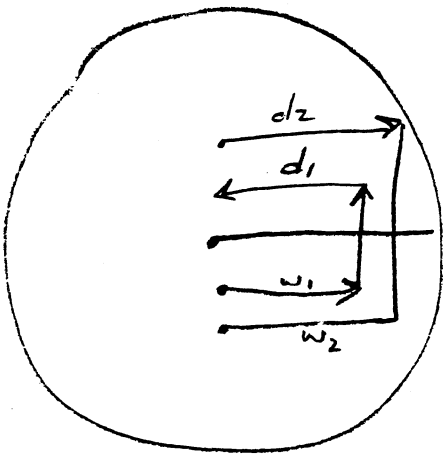
b. when the crop is too tall for hand-measurements, the instrument is mounted on a monopod (similar style as a flag). This necessitates a digital voltmeter be mounted on the monopod so that the instrument output can be monitored.

Figure 1. Schematic of data collection procedure

A. Rows running across the pivot



B. Rows running with the pivot



University of Nebraska Hybrid Evaluation

The seed was planted for our tetraploid hybrid evaluation program. Lack of sufficient S-12 seed resulted in more plots being planted to S-6 than originally planned. There are two irrigation treatments per replication: 100% irrigation (non-stressed) and 33% irrigation (stressed). There is one replication of S-12 and three replications of S-3, S-6, S-57 and Pioneer 3901. Two of the replications for S-3, S-6, S-57 and Pioneer 3901 have 2 neutron tubes per plot (used for soil water balance). In addition, there are also 3 replications of Pioneer 3732. (See Figure 2 and Tables 1 and 2).

Bronson Gardner

BG:rih

cc: M. E. Keener
S. C. Price
D. S. Hill
H. D. Knudsen
J. D. Burrington
T. E. Rooney

1984 Experimental Design - Final Revision

Figure 2

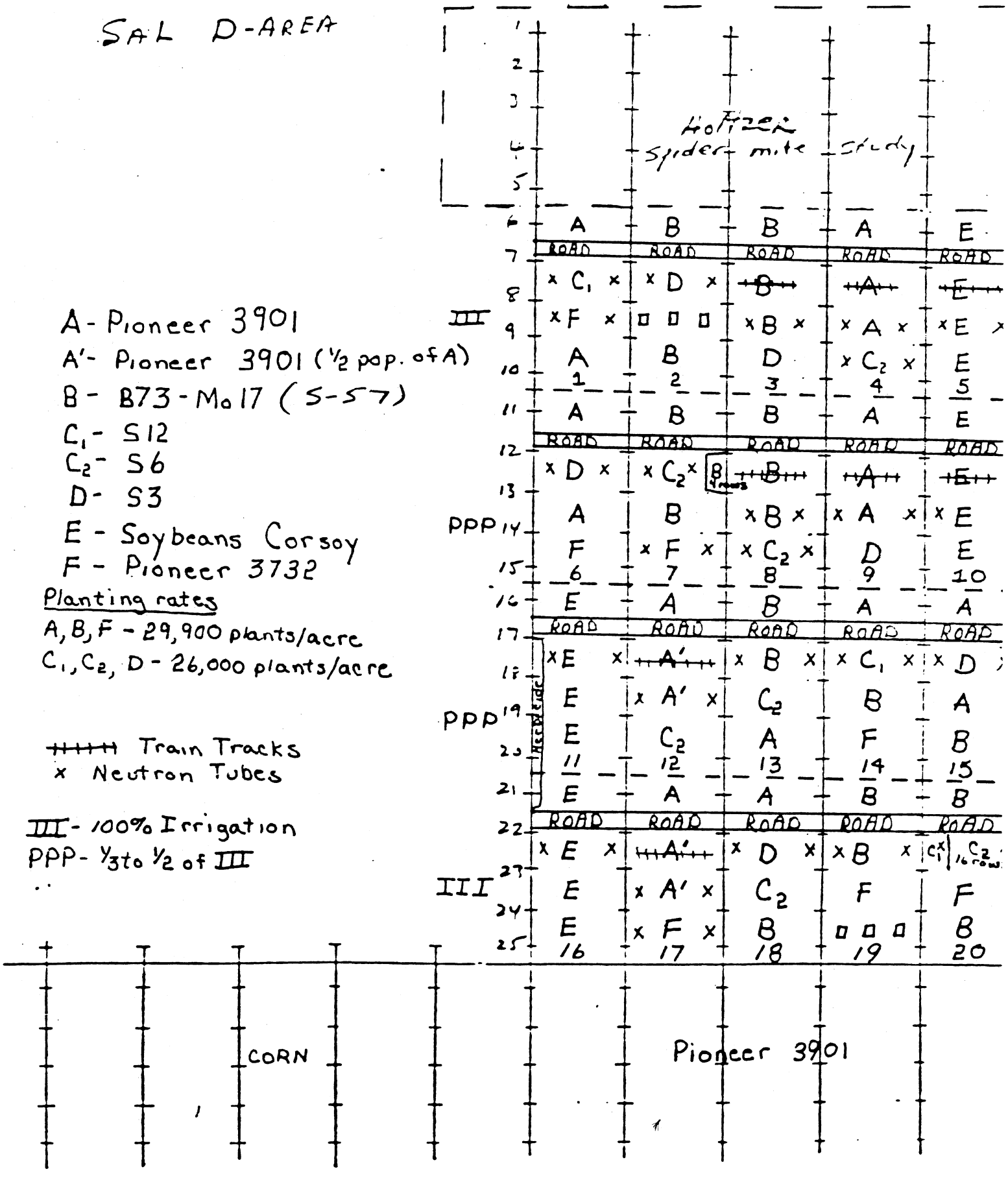


TABLE 1

Hybrids Planted - SAL May 15-17

Plot	A	B	C	Irrigation TRT
1	S-12	P3732	P3901	FULL
2	S-3	Lysimeter	S-57	FULL
3	S-57	S-57	S-3	FULL
4	P3901	P3901	S-6	FULL
5	Soybeans	Soybeans	Soybeans	FULL
6	S-3	P3901	P3732	PARTIAL
7	S-6 (Last 4 Rows on East are S-57)	S-57	P3732	PARTIAL
8	S-57	S-57	S-6	PARTIAL
9	P3901	P3901	S-3	PARTIAL
10	Soybeans	Soybeans	Soybeans	PARTIAL
11	Soybeans	Soybeans	Soybeans	PARTIAL
12	P3901	P3901	S-6	PARTIAL
13	S-57	S-6	P3901	PARTIAL
14	S-12	S-57	P3732	PARTIAL
15	S-3	P3901	S-57	PARTIAL
16	Soybeans	Soybeans	Soybeans	FULL
17	P-3901	P3901	P3732	FULL
18	S-3	S-6	S-57	FULL
19	S-57	P3732	Lysimeter	FULL
20	Rows Rows 1-8 9-24 =S12 S6	P3732	S-57	FULL

*Planting rates for Pioneer 3901 and S-57 = 29,900 (machine planted)

*Planting rates for S-3, S-6, S-12 = 26,000 plants/acre (hand planted)

*Harvest Row Groups: 5,6,7 · 9,10,11 · 14,15,16 · 18,19,20
3(15 row length) = 45 feet per sample = 4 samples/plot

TABLE 2

Rain gauge/Neutron Tube Locations

	A	B	C
1	2 Tubes	2 Tubes	-------
2	2 Tubes	-------	-------
3	-------	2 Tubes	-------
4	-------	2 Tubes	2 Tubes
5	-------	2 Tubes	-------
6	2 Tubes	-------	-------
7	2 Tubes	-------	2 Tubes
8	-------	2 Tubes	2 Tubes
9	-------	2 Tubes	-------
10	-------	2 Tubes	-------
11	2 Tubes	-------	-------
12	-------	2 Tubes	-------
13	2 Tubes	-------	-------
14	2 Tubes	-------	2 Tubes
15	2 Tubes	-------	-------
16	2 Tubes	-------	-------
17	-------	2 Tubes	2 Tubes
18	2 Tubes	-------	-------
19	2 Tubes	-------	-------
20	2 Tubes	-------	-------

NEB.DO

Bronson

MEMO

To: S. C.Price
From: M. E. Keener
Subject: Nebraska trip

Bronson Gardner and I visited the x-corn experiments at the Sandhills Agricultural Laboratory August 20-23, 1984. A second set of physiological data was taken on the five varieties, two diploid and three tetraploid, and two irrigation treatments. This data is comprised of photosynthetic rates, transpiration rates, and canopy temperatures. This data set represents the mid-grain filling period. Data analysis will begin as soon as SAS becomes operational on our computer system.

As we expected, there is a lot of variability in the x-corn plots. The problems seen in Missouri last year under stress conditions are again appearing in the partial irrigation treatment at SAL. That is, there are some problems in pollination. Preliminary indications are that the x-corn varieties are not holding up to the stress as well as the diploid hybrids. This has yet to be confirmed by the dry matter data. The fully irrigated x-corn plots look much better. There may not be any statistical differences in the plots due to the variability in the x-corn plots. However, some of the individual plants in the x-corn plots show very large ears, as long as 12 inches, that have as many as 800 kernels. The kernel size also appears to be larger. Both components could result in a significant increase in yield potential. These observations will be confirmed when the yield data is taken.

ACTION TO BE TAKEN

1. Finish the data analysis.

2. Return to SAL at harvest.

ind.DO

Bronson

MEMO

To: S. C. Price
From: M. E. Keener
Subject: Sohigro and Romney

Bronson Gardner and I were invited to man two booths at Sohigro's semiannual meetings in Indianapolis August 28, 1984. The topics shown included the remote sensing project for APD, the irrigation scheduling project, the hybrid seed purity project, and a general outline of the Biotechnology group. All three of the individual projects were well recieved with the remote sensing and the irrigation scheduling projects recieving the most attention, probably because of the higher visual impact made by this presentation. However, several individuals indicated that they had been less than satisfied by the hybrid purity as indicated by growout results and that some other method was needed. Bronson and I were very pleased with the responses we recieved. Not all of the people were convinced that we were needed but that is to be expected. We consider this to be a valuable exposure to the people in APD. David Hill indicated that our participation in these semiannual meetings would become permanent. We think having some of our people at these meetings every time would be very good. I hope that we can become an intregal part of the program in the future as well as having a booth in their trade show.

The breeding plots of x-corn at Ag Alumni Seeds in Romney, In. were visited on 29 August. All crosses and selfs have now been made. The increase nursery for the x-corn inbreds is not as uniform as I would like for it to be. This may be due to the fact that some of this seed was bulked for the purpose of seed increase in anticipation of filing for variety protection of certain x-corn inbred lines. The ear-to-row nursery looks fairly good with some material looking uniform enough for inclusion in the Ohio Foundation Seed nursery next year. This decision will be made after looking at the winter nursery. We may be able to add up to 7 new inbred lines by next summer.

ACTION TO BE TAKEN

1. Follow up on the invitation to have a presentation at the next Sohigro meeting. Develop a better presentation method to draw people to our display.

2. Visit Romney once more before harvest to make additional evaluations of selected lines and estimate how much seed we will have available from the selfs and the crosses.

3. Evaluate the agronomic and breeding benefits of locating the winter nursery in an area with a climatological regime similar to the Corn Belt.

THE STANDARD OIL COMPANY
RESEARCH AND DEVELOPMENT
WARRENSVILLE LABORATORY

TRIP MEMO

Thunderbolt Farm
August 23-25
Bartlett, Nebraska

B. R. Gardner
Agronomy, Crop Physiology
Biotechnology Group

August 30, 1984

SUMMARY

This trip to Fred Hepler's was made to determine whether any mid-season adjustments needed to be made in our irrigation scheduling experiment. It was determined that no adjustments need to be made. The technique is working at least as well as Fred's water-balance technique. Fred Hepler is generally pleased with SOHIO's research interests and has expressed a desire to continue research with us. Fred expressed dissatisfaction on two points relating to the contract negotiations:

1) SOHIO shouldn't wait until the crop season is nearly over before signing a contract. This allows us an opportunity to "get something for nothing" should the crop fail and we refuse to sign a contract late in the season. For this reason, Fred refused me permission to inspect the crop on this trip until our legal department gave him assurances that the contract would be signed.

2) The second point of dissatisfaction concerns payment for services rendered. The contract fee represents salary payments to the individuals assigned to collect the data. Consequently, these monies need to be made on a timely basis. We originally promised an August 1 payment date, but have since changed that to September 1. This salary money should have been paid Fred regardless of whether a contract was signed , since SOHIO began the experiment.

After conducting an inspection of both center pivots, I am convinced that center pivots can be irrigated on the basis of canopy temperatures. The next step should be a market analysis followed by development of a prototype.

RECOMMENDATIONS

1) Finalize all future contract negotiations before the beginning of the crop season.

2) Conduct a market-analysis for irrigation scheduling based on infrared thermometry.

3) Return to Nebraska to supervise the harvest. The pivots we are experimenting on will be harvested twice: once for silage and once for grain. Consequently, two trips will be necessary.

B. R. Gardner

BRG/rih
30-AUG-84 13:11:34

SOHIO CHEMICAL COMPANY

OFFICE CORRESPONDENCE

September 6, 1984

Dr. Bronson Gardner
Warrensville Research Laboratory
4440 Warrensville Center Road
Warrensville Hts., Ohio 44128

Dear Bronson,

Thank you for the professional presentation you made at the trade show of Sohigro's sales meeting. The impact was felt immediately as managers began asking when remote sensing services will be made available. The exposure gained to this group will be important for insuring successful integration of these and other research projects into APD's marketing effort.

I anxiously await the results of the remote sensing pilot program we field tested this summer. Please let me have a copy of the report when it is completed.

Again, thank you for your efforts in presenting the exhibits and making it such a successful event.

Sincerely,

David Hill

D. S. Hill

cc: J. W. Bibbins
S. J. Price
M. E. Keener

V—5075

SOHIO THE STANDARD OIL COMPANY

RESEARCH CENTER
4440 WARRENSVILLE CENTER ROAD, CLEVELAND, OHIO 44128

November 16, 1984

Mr. David Dunn
Carborundum Center
P. O. Box 156
Niagara Falls, N. Y. 14302

Dear Mr. Dunn,

Dr. Melvin Keener and Dr. Bronson Gardner of the Biotechnology group here at Sohio have refined technology utilizing infrared thermometry to the point of it being a potential commercial opportunity for the scheduling of irrigation for corn. Basically, the technique utilizes the temperature differential between the crop and the ambient air, together with the radiation load and humidity. The technique works basically on the observation that as a crop goes into water stress, it heats up.

In the summer of 1984, they showed that this technology works under actual field conditions. They applied it to a center-pivot system in Nebraska, and a field-flood system in Arkansas. In both locations they found that this technology is as good as or better than existing methods for scheduling irrigation.

They are working with Mr. Herb Knudsen and Mr. David Hill, both of Corporate Development, in exploring the type of business to be entered. We envision working with irrigation scheduling consultants and influential farmers this summer, 1985, to gain added experience with the system, and to gain a better feel for the available markets.

We intend to construct a prototype device consisting of the infrared detector and a microprocessor, which can be mounted on a center pivot system. This device could then automatically switch the center pivot watering system on and off. As we see it, this would greatly facilitate the farmers management of water needs, make his irrigation more economical, and reduce his reliance on water consulting services.

There is no reason why existing irrigation system equipment could not be retrofitted with this device, or that new equipment could not be sold with this device already mounted on it. The latter senario could also be an added inducement to buy a certain center pivot system.

Therefore, we would like to have an opportunity to speak with you and your center pivot contact in Nebraska. We would be happy to travel to Nebraska to discuss this technology with them.

Sincerely,

Steven C. Price, Ph.D.
Group Leader
Biotechnology

SCP:rih
111684
wps.ag3

cc: Dr. R. Rightmire
Dr. J. Burrington
Dr. A. Clark
Mr. H. Knudsen
Mr. D. Hill
Dr. M. Keener
Dr. B. Gardner

THE STANDARD OIL COMPANY (OHIO)
Research and Development
Warrensville Laboratory

TRIP MEMO

UNIVERSITY OF NEBRASKA
16-23 November.1984

LAS VEGAS, NEVADA
24 November - 2 December, 1984

Bronson Gardner
Biotechnology Group

December 7, 1984

This trip to the University of Nebraska was made to conduct preliminary analysis of remote sensing data acquired over our 1984 experimental plots (located near North Platte, Nebraska) by the Jet Propulsion Lab, from Pasadena, California. The imaging system they used is new and has the potential to finally clarify what type of information can be extracted from remote sensing data, not only as pertains to agriculture but also for such areas as geology, hydrology, forestry, etc. This system is still under active development, but can presently be used to gather information in some portions of the solar spectrum. Eventually, the entire spectrum will be covered. At present, the unconventional design of the system, has made it difficult for most computer resource people to understand how to process the data.

The second portion of this trip was attendance at the annual meetings of the Agronomy Society. Several interesting and useful technical papers were presented in the remote sensing sessions. In addition, I made contact with people who have expressed interest in helping us find farmers who would like to test our irrigation scheduling system. I will follow up on these contacts. Their names are Marvin Bauer, Mark Seely, Kris Aase, Blaine Blad, and Jim Heilman. I was invited by Marvin Bauer and Blaine Blad to become associated with a regional/national remote sensing group they are planning to form. This would provide an opportunity to interact with senior scientists who are actively engaged in agriculturally related applications of remote sensing.

One exciting aspect of these meetings pertains to genetic engineering activities. The Natural Plant Institute (Salt Lake City) has developed a system for mapping the genes of corn and other plants, in a similar fashion as is being done for Sohio's seed testing company. They claim that, if they

have mapped the parent lines, they can take an unknown seed and identify its parents. This capability, if real, could be an asset in more rapidly purifying our X-corn lines. It is possible, since they currently have no market outlet for this technology, that the seed company could somehow use their services in providing additional services to their customers.

Independent researchers reported success in tissue culturing mature plants from calluses of wheat, alfalfa, corn, and cotton. I made contact with these researchers. They seem willing to share much of their experience and knowledge, especially in the area of successful protocols. They all agreed on at least one point: there is a strong genotype/media interaction, for whatever reason. Responsive genotypes of each crop have also been identified. Photographs of embryonic cells of each crop showed that the physical appearance of embryonic cells is not the same from crop to crop. The wheat work was done at the University of Utah, the alfalfa work at the University of Alberta, Canada, the cotton work at Texas Tech, and the corn work at Sungene Inc., California. The Sungene researcher invited me, or someone from our group, to take a tour through his lab and discuss tissue culture research. The other researchers were also eager for interaction with other labs.

It was shown that if light intensity levels could be increased by 50% in the lower portion of a plant canopy that grain yields would also be increased by 50%. If corn plants could be engineered with shorter/smaller leaves, then some of this potential might be realized. Ray Jackson, researcher for the USDA and NASA, has proposed the development of the "forever airplane", which is essentially a very lightweight aircraft, with a solar powered motor. If equipped with remote sensing instrumentation, such a craft could be left unmanned at a high altitude. It would then have the effect of being a regional satellite. The technological problem which prohibits its practical implementation is the availability of a lightweight, but energy intense power source (solar cells and batteries).

ACTION:

Provide Dave York, and any other interested parties, the names and addresses of the tissue culture researchers.

Follow-up on those who are interested in helping evaluate our irrigation scheduling technology.

Bronson Gardner

BRG:rih
121284
wps.ab5

CLV-81

THE STANDARD OIL COMPANY
OFFICE CORRESPONDENCE

MEETING MEMO

Date: December 12, 1984

Place: Warrensville

Subject: Irrigation Scheduling

Attendees:
Steve DeSutter
David Dunn
Bronson Gardner
David Hill
Melvin Keener
Herb Knudsen
Steven Price

An informational meeting was held to discuss with David Dunn of SCIPCO's Carborundum Division the irrigation scheduling technology developed by the biotechnology research group. Carborundum is a licensed manufacturer and distributor of Lindsay irrigation center pivots in Brazil. Currently only 1% of Brazil's arable land is irrigated. Potentially, the market for pivots could approach that of the United States. In 1984, Carbomatic sales in Brazil were $5 MM. Lindsay is the second largest manufacturer of center pivot equipment behind Valley. In 1984, Lindsay sold more than 5,000 units to Saudi Arabia, the world's leading consumer of equipment at present.

Mr. Dunn expressed great interest in the irrigation scheduling technology of R&D. Three beneficial areas were identified by Messrs. Gardner and Keener: 1) reduced water consumption; in Nebraska 20% of corn is overwatered; 2) improved application efficiency through better timing of watering; and 3) correction of underapplied irrigated fields.

It was noted that Lindsay has substantial market knowledge and expertise in the irrigation business. It was agreed that a meeting with key management of Lindsay, to be identified by David Dunn, is the next key step in developing the irrigation scheduling business.

Action:

David Dunn contact Lindsay to arrange a meeting January 7 and 8 in Columbus, Nebraska.

David Hill will inform Messrs. Knudsen, Price, Keener and Gardner of arrangements.

DSH

David S. Hill
December 13, 1984

DSH/ap
A655

cc: A. Clark

TO: MELVIN KEENER
TRIP MEMO
RE: FRED HEPLER'S FARM

I WORKED WITH FRED HEPLER AND SEVERAL OF HIS PEOPLE TO DETERMINE THE MOST EFFICIENT METHOD OF COLLECTING CANOPY TEMPERATURES FOR OUR IRRIGATION SCHEDULING PROJECT. WE HAVE NOW IMPLEMENTED A DATA COLLECTION PROCEDURE AND DESIGN SEVERAL FORMS FOR USE IN STORING AND ANALYZING THIS DATA. IN ADDITION, I WROTE TWO COMPUTER PROGRAMS FOR USE ON HIS APPLE COMPUTER WHICH ARE USER FRIENDLY. WE COLLECTED AND PROCESSED DATA OVER A THREE DAY PERIOD.
THE PRELIMINARY INDICATIONS ARE GOOD.
FRED AND HIS PEOPLE FIND THIS TECHNIQUE INTERESTING AND STRONGLY HOPE IT WILL WORK.

ACTION: RETURN TO NEBRASKA ON JULY 10TH TO EVALUATE THE PERFOMANCE OF THE DATA COLLECTION AND ANALYSIS PROCEDURES AND
FORMALLY BEGIN THE IRRIGATION SCHEDULING RECOMMENDATIONS EXPERIMENT.

ACTION: FINALIZE THE CONTRACT WITH FRED

BRONSON GARDNER

February 20, 1985

SPEECH TO THE BIOTECHNOLOGY GROUP

One year ago we met to discuss our biotechnology research effort and how this effort could be made an effective commercial force in the future of Sohio. With a year of experience under our belt, I would like to share with you my thoughts on what has happened and give you a framework for discussing what has and needs to happen for our cooperative effort to be successful.

Sohio is a great company and a strong company, and it is our challenge to build on that strength and greatness with new opportunities that will have enduring value to our society and company.

To build these new opportunities, we need to have a combination of vision and skill. These are the ingredients of success.

We all know people who have visions but no skill in implementing it. We call them dreamers. In the arts, they habituate cafes and constantly talk about "work in progress" that is never completed. In the lab, they are people who have grand designs but do not implement those designs.

On the other hand, there are those who possess highly honed skills but have no vision to work on. Their melancholy lament identifies them. If only I knew what top management really wants me to do. Those without ideas grind out experiments for the sole purpose of gathering the data and compiling it into a report. These technicians' work is done when the report is complete.

In any enterprise, both dreamers and such technicians, regardless of their level, are condemned to ineffectiveness.

Seeing an artist sitting down at his easel, this concept is easy to understand. If I were at an easel with a grand vision of what could be drawn, my total absence of skill would prevent me from translating that vision into a classic piece of art. On the other hand, if an artist of great skill sat down at the easel but had no idea of what he should draw, nothing would be accomplished.

Today, we will talk about the vision of where we are going in biotechnology and the skills needed to accomplish this vision.

Sohio consists of groups of people with charters. Within the scope of their charters, these groups pursue their objectives. In Sohio Oil, for example, there are groups with the objective of operating a profitable business of gasoline stations. There are also charters, of course, in mining copper, the production of coal and in every other area of the Corporation.

Most of the charters in Sohio, and any other company for that matter, involve the optimization of existing businesses. For established opportunities, the facilities and resources are in place, a tradition of how to operate the business is common wisdom and systems are established which have tremendous resistance to change. In short, the picture is almost painted -- a few changes are needed here and there, but the vision and the skills are an integral part of the present business.

The existing businesses of Sohio are the source of our current strength and greatness. Each of us should hope and pray that theses businesses prosper. If they do not, we will not have a chance to pursue our charter to secure a significant part of our company's future.

The charter of this group in this room is to create an important biotechnology business for Sohio.

The Biotechnology Group was started in 1979 as a pure research effort. Additional research resources were added over the next four years and a number of interesting research leads were identified. In 1983 when I first began working with this group, there was a great deal of skepticism within Sohio that investment in biotechnology was prudent; the projects all seemed so long term and speculative.

We worked hard together. We explored opportunities. We analyzed skills. We identified important technologies. After this introspection, it was abundantly clear that the Biotechnology Group could not survive within Sohio if **only** long term opportunities were pursued.

Almost exactly one year ago we got together at Broadway Lab and talked about how a business could be made from biotechnology. We needed to prove that our biotechnology could be turned into money. A vision of pursuing short, intermediate and long term opportunities was outlined: I would be responsible for short term commercialization, and you as a research group would continue working on the longer term opportunities and take a bow when the short term projects were successful.

During the past year, we have made tremendous strides in establishing a strong biotechnology business: the vision of our thrust into biotechnology has been more precisely defined, commercial sales have begun and numerous opportunities are receiving priority consideration for commercialization.

The Vision

The first part of our vision was agreed upon at our meeting last year -- we need a blend of short, intermediate and long term opportunities. This continues to be an important premise for our activity.

During this year a second premise has been established. Our thrust is directed toward a business of agricultural technologies emphasizing our expertise in plant technology. Therefore, our vision is to pursue a mix of opportunities directed toward agricultural technologies.

Let us explore the need for a mix of opportunities. We cannot rely on only one major project to create an important biotechnology business. There are at least two reasons for this.

First, many of the biotechnology opportunities are not large enough in and of themselves to provide a substantial and important business for Sohio. To provide the necessary critical mass for a sustainable business, a cluster of opportunities must be formed.

Second, a broad range of opportunities are needed to provide a commercial knowledge base for our longer range programs; we will have a relevant track record of success on which to build bigger projects. Any of us associated with the commercialization of our seed purity business will appreciate that tremendous lessons are learned even in small projects.

During the past year we have been verbalizing this strategy of pursuing a mixture of opportunities. It continues to make sense: it has received a warm reception in many audiences and, most importantly, it has provided a comfortable framework for all of our activity in this group. Moreover, it is working. This concept remains as an important part of our vision.

The short term opportunities have a high degree of visibility now and give us a strong basis for telling our story, that we are successfully turning biotechnology into money. That kind of a story gets attention at senior management levels and, as we noted on the front page of the business section of the Sunday Plain Dealer a week ago, gets us publicity.

I would like to share with you two warnings about this or any of the other publicity we receive.

First, we are not out to get the publicity even though that's good for our egos. We are out to establish businesses, and we must keep focused on that fact. We dare not lose sight of the objective. We cannot feed ourselves or our families on newsprint.

Second, publicity can be very destructive in a group. This group is no different. As our short term projects become successful, they will receive publicity. As we discussed last year, the entire group should get the credit. We must all share the problems and all share the glory; otherwise, the group will self destruct.

This second warning leads into the last major point I wanted to make about our mix of opportunities -- our mixture is critically interdependent. As Benjamin Franklin said, "We must all hang

together or we will hang separately."

We see the need for patience and large amounts of resources for the longer term opportunities, but we have no prospect of getting either unless we are successful in commercializing and developing the shorter term opportunities. Therefore, if we want to develop longer term opportunities, we need to show that we can in fact successfully develop the smaller opportunities.

On the other hand, the opportunities we are currently developing are not of sufficient size to be an important business. Sohio is not interested in a $5 million business over the long term. Therefore, it would be divested. So, it is critical that longer term opportunities be successfully developed to produce a large, viable business for Sohio.

Thus, we are continuing to pursue a mix of opportunities and all of us must work together to assure the success of the short as well as long term projects.

Now let us take a look at the agricultural technologies part of our vision. I have identified this direction in a draft document on our Agricultural Technology business. You all have a copy of this draft and can see from it a glimmer of what we think is possible.

Agricultural Technologies has three focal points: technical service to the agricultural industry; improved technology for existing crops; and new agricultural industries.

First is technical service to the industry. Through application of our technical expertise to current industry problems we can establish a beachhead in the agricultural technology business. This approach is in sharp contrast with a number of other companies who are getting into the field by acquiring seed companies. Our approach is different, and we should be neither embarrassed that we are not following the the same strategy as others nor overconfident that we have the only formula for success.

During 1984 we began offering our seed purity testing service in to the corn industry and have commercial sales. The help and support for this effort from everyone in this group has been gratifying. With this, our first project, we have started to build a reputation of turning biotechnology into money. We are demonstrating what we can do. In 1985, sales will be at least ten times as great as last year, and we will move our production laboratory to an outside facility close to Warrensville.

We are also well on our way to establishing an irrigation scheduling business. Last year we had a successful field demonstration of one unit applied to corn. While we did not get the higher yields I expected, we did prove that we could save the average center pivot unit about 200 hours of annual operating time, or $1500 per year. With the successful initial demonstration, 25 advanced prototype instruments are being built now for market testing this summer.

We are also discussing with customers the possibility of Sohio supplying a corn tissue culture service. Testing the purity of other seeds, soil condition analysis and other service opportunities are being sought.

Second is improved technology for existing crops. These are generally considered intermediate term opportunities.

This past year we have entered into a joint development agreement with a foundation seed company to conduct an intensive breeding and development program for our x-corn. We suffered an unfortunate setback in this program with the freeze in Florida, but we will be continuing our aggressive program this summer in two locations.

In 1984, we also gave detailed consideration to the commercial aspects of RuBisCo, but found that the projected cost could probably not be justified in the market place. Accordingly, alternative approaches were suggested.

We are looking at a few other possibilities in this intermediate timeframe, but encouragement of more ideas would be welcomed.

Third we plan to start new agricultural industries.

Currently our most prominent prospect is milkweed. Originally we looked at this as a very long term opportunity, but now we have active interest and potential cooperation with a major company to develop a substantial new agricultural industry based on milkweed. This year we will have a thirty-fold increase in our milkweed acreage and a significant agronomic program.

This past year we have also given emphasis to evaluating the potential of limnanthes. This work has been done in conjunction with Sohio Oil to determine whether the limnanthes enhances the properties of gear oils sufficiently to warrant a commercial field trial. Specification tests have been passed and sufficient oil should be available for tests this year.

An opportunity is also being considered in chickpeas. Our important DNA work would also fit into this category of commercial businesses. An improved understanding of these projects in 1985 should give us a better basis for formulating our long range plans.

This discussion is our vision of biotechnology--to create an important biotechnology business for Sohio using agricultural technologies as the vehicle. This vision, in and of itself, is not going to get us anywhere without the necessary skills.

The Skills

Skills are required to implement a biotechnology business just as the skills are necessary in painting a masterpiece. The needed

skills plus the vision are the secret to success.

The skills shape the vision. Indeed, when our cooperation started we first analyzed our skills and then drew a vision based on our existing capability. We need diverse skills and personal responsibility to accomplish our vision.

When the biotechnology group was formed, it consisted of only technical expertise. Some business analysis and assistance was added indirectly, but the group was essentially technical. These were the skills required to develop research leads and pursue them with an experimental program.

When I became involved in the program in late 1983, greater emphasis was placed on action-oriented exploitation of opportunities identified. This approach required that additional skills be brought into the biotechnology group: agreement negotiation skills, interdepartmental coalition building skills, expediting skills, business management skills, sales and marketing skills and production skills. These skills, as well as increased technical staff, were added to our biotechnology effort. Many of you were not here when we met one year ago.

Many people believe that if you create a better mousetrap, people will beat a path to our door. This is false. It has never been true. Scientific effort alone will not lead to commercial success.

We need not only the technical skills that produce the ideas, but we also need production people who can translate those technical achievements into a salable product or service. Even this is not enough.

If we had a great invention and the production, we still need to know the customers which form the market. We must produce a product that can be sold and that has the necessary value to make the business attractive.

These diverse skills are required to successfully meet our objective of creating an important biotechnology business. Our goal cannot be reached with pure science alone.

Personal responsibility. Our individual responsibility encompasses three tasks: to understand the vision, to verbalize skills and ideas for new opportunities to advance and expand the vision; and to take action to turn these ideas into reality.

Our biotechnology team needs to work together to be effective. Cooperation would be difficult at best if it were not for the fact that we are bound together by a common vision. Therefore, a primary responsibility is to understand and take ownership of what we are trying to accomplish.

Second, we need to verbalize our skills and ideas for new opportunities to advance and expand the vision.

I have a friend who jokes, "We need bright creative people who will do what they are told." The waste in such a philosophy is self-evident.

The vision is a framework for individual action. Without our skills and our ideas, it is nothing. Therefore, each of us has a responsibility to make our maximum individual contribution. "We need bright creative people who will take the initiative." We need your willingness to verbalize and champion your ideas for new opportunities. Then, let's see whether it makes sense to actively pursue the opportunity as a part of our mutual commitment to each other. There are no bad ideas -- only ones that have not been put in the proper light for concerted effort. Therefore, it is imperative for each one of us to charitably evaluate every idea.

Finally, we need to be willing to take action. Most people say, "I don't have the authority." I firmly believe that most of the ideas we have can be implemented by us as individuals.

We can make that improvement in the production step; we can do an experiment to verify the validity of our idea; we can write a note identifying the idea and enlisting the support of others. Actual examples of this independent action are becoming common in our biotechnology group. Seed purity testing, x-corn, irrigation scheduling, corn tissue culture, RuBisCo and milkweed all are a result of individual action. People in this group are willing to take action.

We need not only a vision, but we need the skills.

We are involved in a dynamic process. The vision of what we can do in biotechnology will and should be constantly changing as we bring together new opportunities, skills and experiences. This is a good process and an exciting adventure. It is fun for me to be associated with this group.

Finally, we are building a track record of success. It is just a beginning, but we have come a long way in one year. You are all to be congratulated for your individual roles and as a group for the spirit and dedication you have shown. Now we press on to even greater achievements. We have the vision and the skills for success.

Herbert D. Knudsen

HDK/ek

THE STANDARD OIL COMPANY (OHIO)
Research and Development Center
Warrensville Laboratory

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To Company Personnel
On Need-to-Know Basis

ON THE USE OF CANOPY TEMPERATURE TO SCHEDULE IRRIGATION IN HUMID REGIONS

TOPICAL REPORT NO.: 7215

PROJECT NO.: 1590-04

SUMMARY

The utility of infrared thermometry to detect the onset of water stress and hence its utility as an irrigation scheduling device was demonstrated in the Mississippi Delta region of the U.S. Although the site selection was not appropriate for a season long study, four days of data were collected. These data indicate that the techniques (software and hardware) derived are useful as irrigation scheduling devices and that more than one index is needed for humid or sub-humid environments.

M E Keener — 7/1/85
Melvin E. Keener — Date

Bronson R. Gardner — 7/16/85
Bronson R. Gardner — Date

Approved by: S. C. Price
Group Leader, Biotechnology — 6-30-85
Date

Approved by: J. D. Burrington
Research Supervisor — 7/23/85
Date

cc: Complete
J. D. Burrington
S. C. Price
Library

Summary
Biotechnology Group

KEY WORDS: Crop Temperature, Water Stress, Irrigation Scheduling, Corn, Maize, Infrared Sensors, Remote Sensing

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TABLE OF CONTENTS

	Page
TITLE PAGE	i
TABLE OF CONTENTS	ii
OBJECTIVE	iii
RECOMMENDATIONS	iii
CONCLUSIONS	iii
INTRODUCTION	1
MATERIALS AND METHODS	2
RESULTS AND DISCUSSION	3
CONCLUSIONS	4
LITERATURE CITED	5
TABLE 1	7
TABLE 2	8

OBJECTIVE

The objective of this work is to show that canopy temperatures can be successfully used to schedule irrigation in the humid regions (Mississippi Delta) of the U. S.

RECOMMENDATIONS

The results of this work encourage development of a prototype instrument that can be used to schedule irrigation. This in combination with the preliminary result in Nebraska (TR in preparation, Gardner and Keener) indicates that by using multiple indicies, the instrument can be used in arid or humid environments.

1. Obtain market analysis of potential market for a device based on this technology to schedule irrigation.

2. Develop prototype(s).

3. Test prototype.

ACKNOWLEDGEMENTS

The cooperation of Mr. Brad Boyd of Benson Lake Farms, DeWitt, Arkansas is gratefully acknowledged.

CONCLUSIONS

The data presented here gives further proof that the techniques used can be successfully applied to irrigation scheduling. A market analysis of the potential profit for a device to schedule irrigation should be made.

INTRODUCTION

The concept of using canopy temperature to detect the onset and duration of water stress is not new (Tanner, 1963; Weigand and Namken, 1966; Ehrler and Van Bavel, 1967; Aston and Van Bavel, 1972; Bartholic et al.,1972; and Ehrler, 1973). What is new in this area is that small, portable instruments have been developed which make this type of measurement much easier. The theory relating canopy-air temperature differential to crop water status has a sound basis (Jackson et al., 1981). When a leaf is freely transpiring, the cooling properties of the evaporating water keep the leaf temperature cooler than the air. When soil water becomes limiting, the heat load on the leaf builds up because convection and thermal radiation emission are insufficient to dissipate that heat. Thus, the leaf temperature will approach and often rise above the air temperature when soil water is limiting.

Most of the recent work using canopy temperatures has been done in arid regions. Canopy-air temperature differentials have been related to the yield of alfalfa (Reginato et al.,1978), wheat (Idso et al., 1977), maize (Gardner et al.,1981), red kidney bean (Walker and Hatfield, 1979), and barley, sorghum, and soybeans (Idso et al.,1980). Slack at al.,(1981) used canopy temperatures to schedule irrigation of maize in a sub-humid region (Minnesota). However, they utilized a regression approach that restricts its use to that particular region. The authors state that the equation must be rederived for each location.

Three methods based on the theoretical concepts have been derived and utilized in arid regions. The first (SDD) uses only the canopy-air temperature differential (Idso et al., 1977). The second (WSI) also incorporates the vapor pressure deficit (Idso et al., 1981). The third (CWSI) adds the radiation load (Jackson et al., 1981). The third is based on the energy balance of the leaf. The other two are empirical simplifications of the third. Work done in Missouri (Keener and Kircher, 1983) has shown that in arid environments, all three appear to work equally well as a describer of yield losses due to water stress. In humid environments, only the third method appears to be useful in describing yield losses due to water stress. The fourth index used was the standard deviation of the actual canopy temperatures (SDCT). Work by Gardner et al. (1981) has shown that under certain circumstances, the standard deviation will be the first parameter to show water stress. This occurs in fields with highly variable soil types.

Thus, it has been shown that canopy temperatures can be used to describe the effects of water stress on crop yields. The next stage of this work is to show that these techniques can be used to schedule irrigation. Clawson and Blad (1982) concluded that canopy temperature variability can be used to signal the onset of plant water stress in

maize but that the severity of the stress is better indicated by the magnitude of the elevation of the average canopy temperature above that of a well watered reference plot. Geiser et al., (1982) showed that the regression approach of Slack et al., (1981) could reduce the water applied to maize plots (as compared to irrigation scheduling by a checkbook method or resistance blocks) without reducing yields. Pinter and Reginato (1981) showed a good correlation between CWSI and xylem water potential, an accepted physiological measure of plant water stress, for cotton. However, they did no irrigation scheduling using canopy temperatures.

All work to this point in time on irrigation scheduling using canopy temperature has been on small plots (Clawson and Blad, 1982 and Stegman, 1984) or has only alluded to the possibility of using canopy temperature as an irrigation scheduling tool. This work describes a technique utilizing canopy temperatures to schedule irrigation on a 100 acre field in south-central Arkansas.

MATERIALS AND METHODS

The work was done with the cooperation of Benson Lake Farms, Inc. of DeWitt, Arkansas. The field was located approximately 10 miles southwest of Stuttgart, Arkansas. The predominant soil types in this field were Rilla silt loam and Herbert silt loam. Ring Around 1502 (a single cross maize hybrid) was planted April 15-16, 1984. The row direction was north-south. At the time of the measurements, the maize was about one week from tasseling. This area is part of the Mississippi delta region. The field is rolling with some of the hills having 3-5% slope. The length of these slopes were no more than 100 feet. The irrigation system was a travelling big gun. The water was obtained from a well. There were 9 runs (irrigation paths). Two guns were used for this field. Each pass of a gun took 10 hours with approximately 1.75 inches of water applied each pass. This was more than could infiltrate in some of the areas, resulting in runoff and some erosion.

Before each set of canopy temperature measurements, solar radiation (Licor model 200S pyranometer), wet bulb, and dry bulb temperatures (Psychro-Dyne model 2014 battery powered psychrometer) were measured. The windspeed was estimated to the nearest 5 MPH. Approximately 15 canopy temperature measurements were made 20 rows west of each gun path using an Everest Agritherm model 112 infrared thermometer. An extension pole was used to get the sensor above the top of the crop. A Fluke (model 8024B) portable multimeter was used to remotely read the temperature.

The decision whether to irrigate was based on the following values of the four indices; SDD greater than -2°C; WSI greater than 0.2; CWSI greater than 0.6; and SDCT greater than 1.3°C. These values were determined from existing literature, discussions with other

scientists, and subjective judgement by the authors. A computer program (Appendix A) was written to take the raw data, calculate a value for each of the indicies, and make a recommendation on each index on whether irrigation was necessary. Four days of data are reported here.

RESULTS AND DISCUSSION

Yields were low on this field (approximately 90 bu/acre). The primary reasons were highly variable soils and the application of too much water per irrigation. On the ridges, the soil was eroded enough to expose the clay subsoil. The infiltration capacity of this part of the field was much lower (approximately 0.7 inches/hour) than the application rate of the water (1.75 inches/hour). This caused substantial water runoff, causing further erosion. It also created uneven water distribution within the field with some parts receiving less than 0.7 inches of irrigation water, while other parts of the field received more than 2 inches of water. This also resulted in some ponding of water in the lower areas that reduced stand and yields. This field did not have the uniformity necessary for a good test of the technique. This, plus other reasons, lead to the decision not to use this field for a season long study. However, four days of data were collected in an effort to show the techniques would work in a humid area, and the selection criteria for recommending irrigation were reasonable.

Table 1 provides a summary of the weather conditions and the four indices from June 20-23 at the Benson Lake Farms. In a separate report (Gardner and Keener, 1985), we show that the WSI index is the preferred index for general irrigation recommendations, although the other indices, especially the SDCT (standard deviation of crop temperature) contain important information.

Figure 1 shows the relationship between SDD and vapor pressure deficit (VPD). Since all the data points are below the SDD-VPD boundary line (indicating the plants are well watered as discussed in Gardner and Keener, 1985) we conclude that none of the irrigation runs required irrigation. However, the SDCT data in table 1 indicates that runs 3 and 4 were exhibiting moisture stress on June 23. These values of SDCT are relatively high (3.1 and 3.0). Thus, the need for irrigation in some parts of the field is a certainty.

The question now arises, should an irrigation recommendation for runs 3 and 4 be based on the Idso index or on SDCT? The answer to this question would depend on the priorities of the farmer. The Idso index indicates that the majority of the crop did not require irrigation. A substantial percentage (around 20%) of the field was severely eroded and the plants there were small. Later analysis of this area showed yields were extremely low (5-40 bu/acre). On June 23, the farmer would have been faced with the following decision: (a)

irrigate according to the requirements of the severely eroded area and thereby over-irrigate the majority of the field or (b) wait until the majority of the field requires water. The farmer would need to consider the cost/benefit of each decision, including potential yield losses in the majority of the field as a result of nutrient leaching caused by over-irrigation. The erosion problems in this field suggest that this farmer has probably been over-irrigating for some time and should reduce the volume of water applied to his field.

When this study was initiated, there was no consistent information to indicate which of the indices would give the most consistent selection criteria or what that selection criteria should be. Previous experience has indicated that SDCT often is the first index to show the onset of water stress. We found this to be true in this limited study.

In very uniform fields the SDCT index will not show stress since it is based on the variability of the canopy temperature. It has been shown (Keener and Kircher, 1983) that the SDD index gives eratic results in low radiation, high humidity conditions. However, under low humidity, high radiation conditions, SDCT is an excellent criteria. The CWSI and WSI indexes share a common fault, that is at low humidity, the baselines converge allowing less margin for error. However, they are both superior to the SDD under all conditions. From this study, the CWSI selection criteria does not appear to add much information. This work, the Nebraska work and that of Stegman (1984), indicates that the WSI selection criteria of 0.2 is appropriate for beginning irrigation. The validity of these criteria should be checked further.

This experiment provided a "worst-case" situation to test the usefulness of canopy temperature measurements in making irrigation scheduling decisions. Instead of a relatively uniform field, as was used in Nebraska, this field was highly variable. This data shows that the technique is sensitive, but that more than one index is essential for making a proper interpretation of the data. The WSI index is appropriate for indicating whether a field as a whole needs irrigation, but the SDCT indicates that known (or unknown) specific areas require more water.

CONCLUSIONS

The technique appears to work well in humid environments. It is apparent from this work and the Nebraska work (Gardner and Keener, in preparation) that several indicies must be used because a single index does not appear to cover all possible types of fields and environments. It may be that some operator subjectiveness will be necessary when a field is highly variable. The decision to irrigate may be based on (a) irrigation requirements of specific areas or (b) irrigation requirements of the field as a whole. This decision will

be affected by a cost/benefit analysis, including yield reduction due to leaching and erosion.

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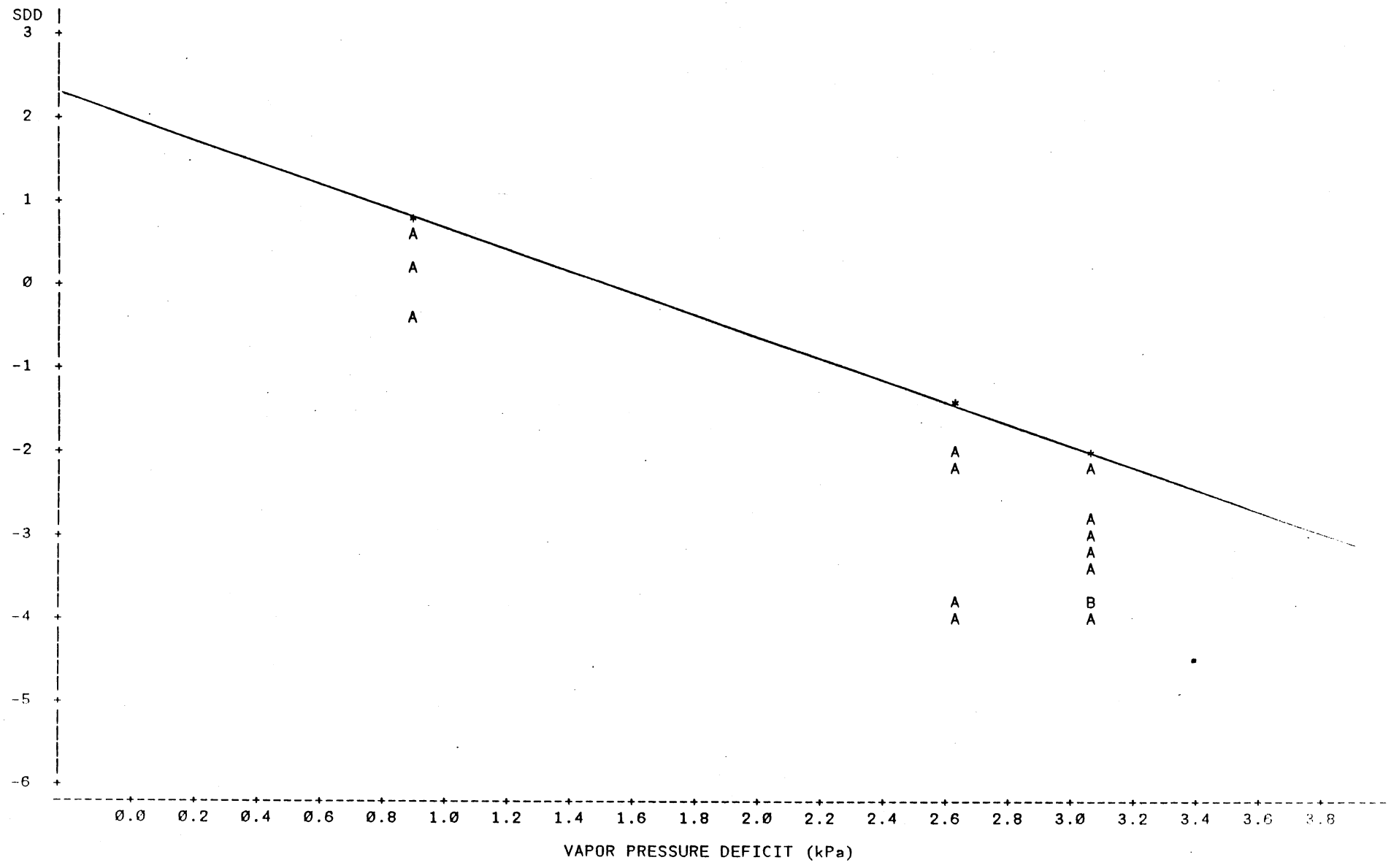
Table 1. Summary of the environmental conditions and the values of four irrigation scheduling indices for the Benson Lakes Farm on June 20-23, 1984.

Run	Date	Air TEMP (C)	Crop TEMP (C)	SDD INDEX	IDSO INDEX	JACKSON INDEX	SDCT	SOLAR RAD (W/m2)	VAPOR PRESSURE (kPa)	RELATIVE HUMIDITY (%)
1	21	34.5	31.20	-3.30	-0.26278	0.45132	0.6	1000	3.07442	43.7799
1	22	35.5	32.00	-3.50	-0.30577	0.41245	1.5	970	3.06609	46.9469
1	23	34.0	31.90	-2.10	-0.15817	0.52397	0.8	1100	2.63421	50.4725
2	20	27.0	26.50	-0.50	-0.66286	0.64703	0.3	480	0.90587	74.5899
2	21	34.5	31.50	-3.00	-0.20265	0.48550	0.7	1000	3.07442	43.7799
2	22	35.5	31.40	-4.10	-0.42630	0.34159	0.5	970	3.06609	46.9469
2	23	34.0	32.00	-2.00	-0.13546	0.53662	0.8	1100	2.63421	50.4725
3	20	27.0	27.61	0.61	-0.13550	0.97119	0.7	480	0.90587	74.5899
3	21	34.5	31.70	-2.80	-0.16256	0.50829	1.2	1000	3.07442	43.7799
3	22	35.5	31.70	-3.80	-0.36604	0.37702	0.5	970	3.06609	46.9469
3	23	34.0	29.90	-4.10	-0.61235	0.27103	3.1	1100	2.63421	50.4725
4	20	27.0	27.10	0.10	-0.37780	0.82225	1.0	480	0.90587	74.5899
4	21	34.5	32.20	-2.30	-0.06234	0.56526	0.5	1000	3.07442	43.7799
4	22	35.5	31.80	-3.70	-0.34595	0.38883	0.9	970	3.06609	46.9469
4	23	34.0	30.10	-3.90	-0.56694	0.29633	3.0	1100	2.63421	50.4725

Figure 1. Relationship between SDD and vapor pressure deficits for the Benson Lakes Farm data, collected June 20-23, 1984. The asterisks indicate the SDD-VPD boundary.



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OFFICE CORRESPONDENCE

August 16, 1985

YC FLP
Jim Kahl
David Hill

cc: D. Bond
J.D. Burrington
S. C. DeSutter
B. R. Gardner
C. T. Jagatich
M. E. Keener
K. A. Mueller
S. C. Price

J. D. Dunn
Niagara Falls, NY

Transfer of
Irrigation Scheduling Project

We are interested in transferring the irrigation scheduling project to Engineered Materials at an early date and in a manner that will maximize the success of this business in Engineered Materials. The success of our prototype demonstration program and the plans for commercialization of this instrument in 1986 make this a very appropriate time for this transfer.

Our early inception of this project was put together in an opportunity plan as attached to this letter. You have seen a copy of this document, and it has essentially not changed since it was approved as a basis for initiating this business venture. It is our plan to use the market and experience during the summer of 1985 to update this Business Plan for 1986.

The success of our program this summer in the field demonstration of the instrument on corn has led us to establish the relatively arbitrary objective of having 400 commercial units available in June of 1986 for sale in four or five target areas within the country using different channels of distribution to identify which would be most successful in penetrating the market. These target market areas would be strictly limited by geography to get some feeling of how well we could penetrate the individual market using the various channels in distribution. Our initial thoughts regarding the areas selected would be to choose those areas coinciding with our target areas for the placement of the demonstration units during the summer of 1985. The sales price for these units has not been established but should be based on the value of the instrument as demonstrated in the program this summer. Currently, we believe the value to the farmer would be in the range of $5,000 - $10,000 but it could be higher or lower depending upon its individual use.

Financially, we would expect to spend about $300,000 through the remainder of 1985 for internal charges, external contract work on the design of the instrument and contracts to obtain the necessary market and sales information. Very roughly for 1986, we would expect another $200,000 to be spent on the completion of the design and the engineering activities that would allow us to manufacture the 400 commercial units for 1986. In 1986, we would expect the cost per unit to be about $1,500.

With respect to people, we have Emil Pierson under contract with us to conduct the field program. His contract is for six months and extends through the end of October. Another major player is Keith Mueller who is the engineer coordinating the design and manufacturing details for us. He has been doing an excellent job of pulling all the factors necessary to commercialize this

instrument together and is critical, in my judgment, for the success of the project. Other people in Corporate Development, David Hill and Steve DeSutter, are spending only part-time on this project. This is also true of Melvin Keener and Bronson Gardner. The main workload is being accomplished under contract with our internal people in C^2IS and at Design Continuum. In addition, we have contracts with SRI in Lincoln, Nebraska, to monitor the field activities for us.

I think it is important for us to reach an understanding as to the people and finance of this project as we go through this transition. We have a strong interest in your success with this business opportunity and want to do everything we can to help you.

Herbert D. Knudsen

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Attachment

Draft # 3
29 August 1985

A GENERAL METHOD FOR GENERATING ALGORITHMS TO SCHEDULE IRRIGATION FOR NEW CROPS

M. E. Keener and B R. Gardner

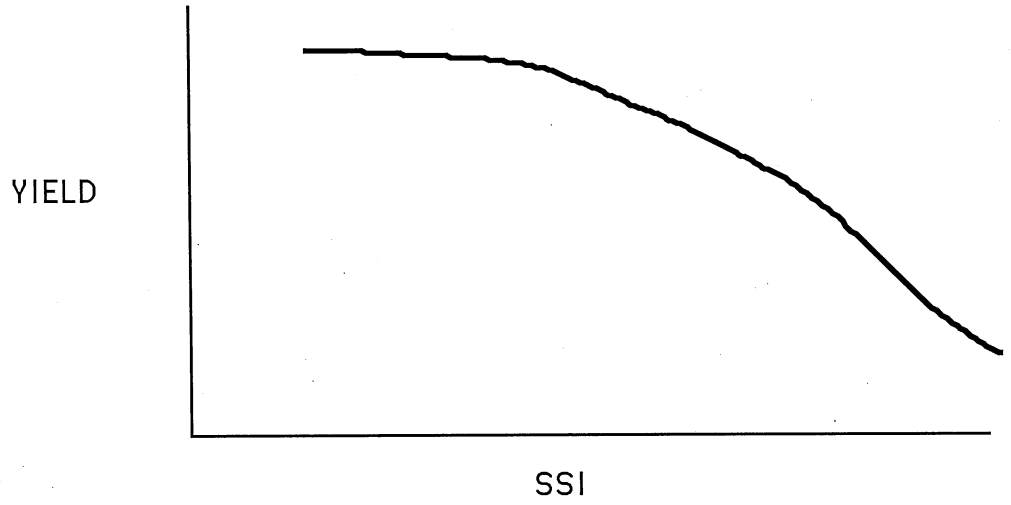
INTRODUCTION

For the Scheduler to be a viable market product, it must be able to accurately schedule irrigation on a number of crops. We are proposing a general protocol for generating the data necessary to accomplish this task. This protocol should be applicable to all crops with some minor modifications. We propose developing a data set that relates economic yield to SSI (Sohio's stress index) and water use to SSI. These two relationships will allow a user to determine what value of SSI he chooses to irrigate and what his economic return will be.

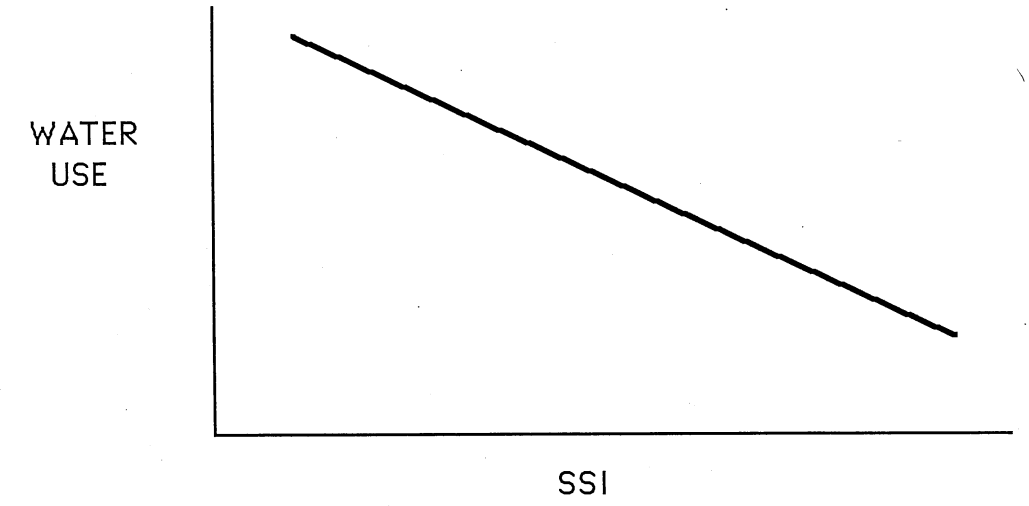
METHOD

The following experiments are to be conducted for each crop. The description will pertain to crops that produce an economic yield. The description of the experiments for crops such as turf will be made later. At this time we see no reason to derive a new well watered baseline for each crop. The inportant thing is at what SSI maximum yield occurs. We propose to use the well watered base line currently being used for corn for new crops, since this appears to be a linear function. Then experiments will be run to determine at what value of SSI that maximun yield occurs.

Each experiment would have a number of treatments where the crop would be irrigated at SSI values of 0.0, 0.2, 0.4, 0.6, etc. Each treatment would have 3 replicates. SSI data would be taken from each plot daily and each plot would be irrigated for the appropiate treatment level. Records of the water applied to the plot would be kept and final yields would be determined. This data would allow the formation of the following types of graphs.



This graph will allow a user to determine at what SSI he chooses to irrigate based on his other management descisions such as fertilizers applied, herbicides applied, etc. In some crops, there are other considerations besides absolute yield. Quality is important in crops such as grapes, sweet corn, potatoes, etc. For these crops, quantity and quality of yield will have to be monitored. Another piece of information needed is shown on the next graph.



With this information, a user can determine his maximum irrigation water needs for the season and can calculate his costs for that water. This will allow for profit maximization. These experiments will need to be conducted in an area where rainfall is not

a factor. The user can take his normal rainfall patterns in to account when using this data to calculate his water costs.

At this time, we would prefer that this work be done by contract researchers under our supervision. We anticipate a cost of approximately $10,000 per crop, location. Because of the differences in weather patterns from year to year, a single year and a single location would not give enough data for development of these curves. There are two possibilities to solve this problem. One is to run multiple year studies at a single location. Another is to have several locations in a single year. Both have faults. Probably the best compromise is to have at least 2 years at multiple locations. The logic behind this suggestion is that even widely different locations may tend to have similiar weather patterns within a single year. Different locations are a must because of differing soil types, management practices, etc.

CONCEPT 1

DISPLAY

1 6 11 16 20

```
CROP___ FIELD___ SPL___
ENTER CROP I.D.#

 01 CORN   04 SORGHUM
 02 TURF   05
 03 MULO

PRESS "?" FOR HELP
```

CROP

```
CROP02 FIELD___ SPL___
ENTER FIELD I.D #

 01
 02
 03

PRESS "?" FOR HELP
```

FIELD

```
CROP02 FIELD21 SPL.
PRESS "T" TO SAMPLE
 1.CANOPY TEMP   40
 2.AMB. TEMP     75
 3.HUMIDITY      35
 4.RADIATION    500
 5.STRESS INDEX  .21
PRESS "C" TO CALCULATE
```

T

```
CROP02 FIELD21 SPL.13
 CANOPY TEMP      40
 AMB TEMP         75
 HUMIDITY         35
 RADIATION       500
 AVERAGE STRESS  .21
IRRIGATION NOT
RECOMENDED
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C

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Warrensville Research Center

PRIVATE

September 6, 1985

Bronson Gardner
Warrensville Laboratory

Dear Bronson:

Confirming our discussion, if for any reason the irrigation sensing project should not require your help and if it is mutually agreeable with the people concerned, it is our intent to bring you back into Corporate Research.

The purpose of the transfer is to enhance the project's chances of success. As we discussed, we want to develop an organizational culture where key personnel are transferred as part of the technology transfer process. Spending time with a business group is excellent training for a Corporate Researcher. For these reasons, we want the transfer of people to the businesses and back to Corporate Research to be an easy, comfortable process.

As I indicated, there can never be a guarantee of any job -- even if you don't transfer. But I wanted you to know we consider your performance to be excellent. It is clearly in our best interest to bring back into Corporate Research people who have successfully created new business opportunities when their mission with a business unit is finished. Your transferring with the project is important to us because we achieve success only when a business unit successfully commercializes our discoveries. Since this is one of the first attempts at technology transfer through the transfer of people, we are anxious that this go well. So if you have any other concerns, please let me know.

R. A. Rightmire

RAR:af
cc: J. D. Burrington
D. B. Anthony
A. H. Clark
D. Dunn

SOHIO

Sohio Engineered Materials Company

Memorandum

PERSONAL & CONFIDENTIAL

To: B. R. Gardner

Date: September 9, 1985

From: J. D. Dunn

Copy to: M. E. Keener
G. S. Mycio

Subject: IRRIGATION SCHEDULING PROJECT - ORGANIZATION

Attached is the approved organization chart for the Irrigation Scheduling Project.

With your concurrence, I will process the necessary paperwork to implement the change. As we discussed, I envision your responsibilities to be in two areas. First, and foremost, is your involvement in ensuring that we have a next generation prototype for next summer. Concurrently, you should begin identifying other crops or areas where the Scheduler can be adopted. As a third priority, but one that is very important, you need to identify or propose the products that might complement the Scheduler.

I understand you discussed the move with Bob Rightmire, and he again stated his assurance that if the project were abandoned for any reason, you would have a position in the Corporate Research group.

I'm really looking forward to having you on our development team.

JDD/kav
Attachment

IRRIGATION SCHEDULING PROJECT

	CURRENT ORGANIZATION		PROPOSED ORGANIZATION	
ASSIGNMENT	RESPONSIBLE	REPORTS TO	RESPONSIBLE	REPORTS TO
OVERALL PROJECT	HERB KNUDSEN (Corporate Development)	FORREST POSKA	DAVID DUNN (Engineered Materials)	LUIZ KAHL
PROJECT MANAGER	DAVID HILL (Corporate Development)	HERB KNUDSEN	DAVID DUNN	LUIZ KAHL
SALES & MARKETING	STEVE DESUTTER (Corporate Development)	DAVID HILL	STEVE DESUTTER (Engineered Materials)	DAVID DUNN
	BOB RUSIN (Engineered Materials)	DAVID DUNN	BOB RUSIN (Engineered Materials)	DAVID DUNN
TECHNICAL	BRONSON GARDNER (Corporate Research)	MEL KEENER	BRONSON GARDNER (Engineered Materials)	DAVID DUNN
	MEL KEENER (Corporate Research)	STEVE PRICE	MEL KEENER (Consulting)	STEVE PRICE
FIELD TESTING	EMIL PIERSON (Contract Person)	DAVID HILL	EMIL PIERSON (Contract Person)	DAVID DUNN
ELECTRONICS/SENSORS	C. JAGATICH (Part-Time)	C²IS	C. JAGATICH (Part-Time)	C²IS
SOFTWARE ENGINEER	DAVID BOND (Part-Time)	C²IS	DAVID BOND (Part-Time)	C²IS
PROJECT ENGINEER	KEITH MUELLER (Corporate Engineering)	DAVID HILL	RALPH FELICE (Engineered Materials)	STEVE WEEKS

10 September 1985

To: S. C. Price

From: M. E. Keener

Subject: Promotion for B. Gardner

Given the successful transfer of the irrigation scheduling project from Corporate Research to Engineering Materials, I think this is an appropiate time to request a promotion for Dr. Bronson Gardner. The fact that this project is of sufficient interest to a business unit should be sufficient evidence for the promotion request. In Dr. Gardner's last performance appraisal, I indicated that a promotion should be considered within the next two years. Due to the rapid movement of this project, I think that timetable should be moved up. Dr. Gardner's work on this project was invaluable in making the project succeed. Many hours were spent at remote locations to insure the success of the first phase of the project. He has also explored opportunities for moving this project into new crops. I think the work that has been done by Dr. Gardner is sufficient for promotion. Please begin the necessary paperwork to help obtain a promotion for Dr. Gardner.

THE STANDARD OIL COMPANY (OHIO)
Research and Development Center
Warrensville Laboratory

RESTRICTED
To Company Personnel
On Need-to-Know Basis

PERFORMANCE OF CANOPY TEMPERATURE WATER STRESS INDICES FOR SCHEDULING IRRIGATION ON CORN CANOPIES IN ARID REGIONS

Topical Report No.: 7580
Project No.: 8401-04

RESTRICTED

SUMMARY

Based on experiments conducted in 1984, this study demonstrates that corn can be successfully irrigated in arid regions using remotely sensed canopy temperatures. Yields of two 150 acre center pivots, one scheduled with conventional technology (control) and the other with remotely sensed canopy temperatures, were compared. The control yielded 19.1 tons/acre with 12.27 inches applied (irrigation and rainfall) and the experimental yielded 19.3 tons/acre with 11.63 (irrigation and rainfall) applied. The primary algorithm for accomplishing this is the Idso index. The inputs required are: canopy temperature, relative humidity and air temperature. A second water stress index, known as canopy temperature variability, is useful as a backup to the Idso index or in situations where a field is non-uniform. This work compliments a previous study (T.R. #2215) documenting use of these indices in humid regions during 1984.

B R Gardner (MER) — 2/27/87
Author: B. R. Gardner
Senior Research Scientist

M E Keener — 2/27/87
Author: M. E. Keener
Research Associate

S. C. Price — 3-4-87
Approved by: S. C. Price
Group Leader, Plant Biotechnology

J. D. Burrington — 3/5/87
Approved by: J. D. Burrington
Research Director, Life Sciences

cc:

Complete	Summary
B. J. Bulkin	Biotechnology
J. D. Burrington	Process Biotechnology
A. Clark	
D. Dunn	

TABLE OF CONTENTS

SUMMARY ..... *i*

TABLE OF CONTENTS ..... *ii*

OBJECTIVES ..... *iii*

RECOMMENDATIONS ..... *iii*

ACKNOWLEDGEMENTS ..... *iii*

INTRODUCTION 1

MATERIALS AND METHODS 2

RESULTS AND DISCUSSIONS 3

- SDD and Idso Indices 3
- Jackson Index 5
- CTV Index 6
- Diff Index 6
- Measurement Resolution 7

CONCLUSIONS 7

REFERENCES 8

OBJECTIVES:

The objective of this work is to show that canopy temperatures can be successfully used to schedule irrigation on corn canopies in the arid regions (Great Plains) of the U.S.

RECOMMENDATIONS:

From the results of this work, results reported in the literature, and the Arkansas Study (Keener and Gardner, 1985), we think that the methods used to schedule irrigation may be universal. Recommendations are:

1. Evaluate the response of this technology for other crops, such as cotton, sorghum, soybeans, vegetable and tree crops.

2. Use an inexpensive silicon cell to detect solar radiation, instead of the expensive thermopile types.

3. Do not measure windspeed. Instead assume within the software that windspeed is held constant at 5 miles per hour.

4. Reduce the critical value of the Idso index to 0.1, instead of the current value of 0.2. This would result in a virtual elimination of the CTV and DIFF indices, two alternate indices of water stress proposed in the literature.

Infrared thermometry can be used to schedule irrigation in corn in arid areas. The minimum inputs required are: canopy temperature, relative humidity and air temperature. Windspeed and solar radiation are optional parameters.

ACKNOWLEDGEMENTS:

The cooperation of Fred Hepler, Brian (Buck) Barelmann, John Ludwig, Phyllis Stille and Debbie Dallegge of Thunderbolt Ranch is gratefully acknowledged.

INTRODUCTION

Miller and Saunders (1923) demonstrated that temperature differences between stressed and non-stressed corn, sorghum, soybeans and cowpea plants are directly related to differences in transpiration. Clum (1926) observed this principle for waxbeans, cabbage, lilac and fuschia. His paper contains an excellent review of preliminary research conducted between 1880 and 1920. Temperature measurements were not viewed as a practical method of monitoring moisture stress since the only available technology for measuring crop temperatures were relatively crude thermocouples. It was not until the early 1960's that portable infrared thermometers became available to agricultural researchers.

These early infrared thermometers, although portable, were bulky, hard to calibrate and relatively expensive. Monteith and Szeicz (1962) and Tanner (1963) were the first to use infrared thermometers to measure crop canopy temperatures. Monteith and Szeicz (1962) demonstrated the dependence of crop temperature on stomatal resistance, the plant parameter which controls transpiration.

Using experimental and theoretical data, Aston and van Bavel (1972) concludes that plant temperatures could be used in two ways to schedule irrigation. One method requires a reference. One suggested reference is the temperature difference between an area known to be well-irrigated and the area under question. Another suggested reference is air temperature detectable differences between a field and the reference would indicate the need for irrigation. When air temperature is used as the reference, the comparison is known as the Stress Degree Day (SDD) (Idso et al., 1977). When a well-irrigated area is used as the reference, the comparison is known as the Temperature Stress Day (TSD) (Gardner et al., 1981). Blad et al., (1981) concluded that 1300-1500 solar time is the optimum time for measuring canopy temperatures to assess crop water status. Mtui et al. (1981) showed that corn genotypes exhibit detectable temperature differences under well-watered conditions. The magnitude of these differences are small (less than 1 degree C), however, and should not significantly affect the use of canopy temperature measurements for irrigation scheduling. The TSD will also be referred to as DIFF (difference between the dry and wet side of the pivot).

The second method proposed using a cropped field as its own internal reference. Since "all fields are inhomogeneous regarding soil properties and infiltration during rain or irrigation", it is expected that an increased temperature variability within a field (relative to well-watered temperature variability) will signal the onset of plant water stress. This method has been labeled CTV (Canopy Temperature Variability) (Clawson and Blad, 1981). Hatfield et al., (1984) showed that the CTV patterns could not be used to indicate the amount of water needed by a crop, but were a sensitive indicator of uneven distribution of water late in a drying cycle. They also showed that 30 samples are statistically required to estimate canopy temperatures of a moisture stressed field within 1 degree C. To estimate canopy temperature within 0.5°C requires 40 samples.

Three additional approaches have been proposed, Idso et al., (1981) proposed a technique for normalizing the SDD. His approach theorizes that the SDD is a function of the vapor pressure deficit of the air. The normalized SDD will be referred to in this paper as the Idso Index.

The most sophisticated approach is that of Jackson (1982), who used energy balance equations to derive a Crop Water Stress Index (CWSI) which is a function of the SDD, the vapor pressure deficit, air temperature, windspeed and solar radiation. The CWSI will be referred to as the Jackson Index.

Geiser et al., (1982) used a regression approach to relate SDD to relative humidity, solar radiation and available soil moisture. The inclusion of the soil moisture term restricts this approach in that calibration coefficients must be developed for each location. Consequently, this approach was not considered.

MATERIALS AND METHODS

This work was done with the cooperation of Thunderbolt Ranch of Bartlett, Nebraska. The center pivots on which this work was done are located approximately 15 miles northwest of Bartlett, Nebraska. The soil types at this site are Valentine sands. Two center pivots were used in this study. Pivot #39 was designated as the control pivot. This pivot was irrigated according to the proprietary technique developed by Fred Hepler. Irrigation on pivot #38 was scheduled according to the output of a computer program which calculated daily values of SDD, CTV, TSD, the Idso and the Jackson indices. The details of the cultural practices for each pivot are summarized in Table 1.

Each pivot has an access road which runs to the center of the pivot. When these pivots were operated, the controls were set so that an irrigation cycle began and ended at or near this access road. The side of the road which was irrigated first during an irrigation cycle as designated as the "dry" side of the pivot. The side of the road which was irrigated last during an irrigation cycle was designated as the "wet" side of the pivot. Thus, when an irrigation cycle was completed, the wet side would have approximately 2 days more stored soil water than the dry side.

Beginning of July 10, 1984 canopy temperatures were measured daily on the wet and dry side of each pivot. Measurements were made on two rows located approximately 250 feet on either side of the pivot. Canopy temperature measurements were made between 1400 and 1600 local time. Approximately 25-30 observations per side were made. Canopy temperatures were made with an Everest Agri-therm Infrared Thermometer. The Agri-therm has an accuracy of 0.5°C and a resolution of 0.1°C. The spot size seen by the Agri-therm is calculated as D/20, where D is the distance to the target.

Before each set of canopy temperature measurements, solar radiation (Li-Cor Model 200S pyranometer), wet bulb and dry bulb temperatures (Psychro-Dyne Model 2014 psychrometer) were measured. Observations were also made concerning canopy height and leaf condition (Tables 2-8). An extension pole was used to elevate the Agri-therm above the top of the canopy after the crop grew taller than the observer. Preliminary studies indicated that canopy temperatures could be measured when the crop was smaller than 30 inches high, provided measurements were made oblique to the row direction. Provided care was taken to minimize the amount of soil viewed, there were no statistical differences between canopy temperature means obtained from a hand-held set of measurements or from a single location while standing on one of the pivot towers. This minimization was achieved by measuring all canopy temperatures approximately perpendicular to the row direction throughout the season. Canopy temperatures were measured from the hand-held mode (observer walking the length of the pivot), in order to insure that sufficient data on canopy temperature variability was obtained.

After the data were collected, five irrigation indices were calculated. The critical values (value at which the need for irrigation is indicated) were: a) if SDD was greater than -2.0 b) if CTV was greater than 1.0 c) if TSD was greater than 1.0 d) if Idso's index was greater than 0.2 e) if Jackson's index was greater than 0.7. Recommendations for each index were calculated on a daily basis (Table 9). Brian Barelmann then decided whether or not to irrigate. His decision was based on whether two or more indices indicated the need for irrigation.

RESULTS AND DISCUSSION

The various irrigation scheduling indices resulted in fourteen irrigation events on the experimental pivot (Table 9). Preliminary training and evaluation resulted in the first irrigation being conducted on July 12 instead of July 10. Inspection of table 9 shows that the indices did not always agree on whether or not stress was present. The reasons for this disagreement will be discussed in the following sections.

SDD and IDSO Indices

The Stress Degree Day index (SDD) was the index most subject to false indication of stress. It seldom indicated the lack of stress when the other indices indicated stress, but it often was the only index which recommended irrigation. These results make the SDD questionable in terms of its reliability. The reliability of the SDD may be related to the selection of -2°C as the critical value for stress detection, regardless of the vapor pressure deficit (VPD) or ambient temperature.

Table 9 shows that the Idso index did not recommend irrigation unless at least one other index also recommended irrigation, with the single exception of the August 27 data (Figure 1). Consequently, we consider the Idso index as the most reliable of the indices used, at least for the arid climate of Nebraska.

To investigate the possibility of a dynamic critical value of SDD, we examined the relationship between SDD and VPD (Figure 2). Figure 2 shows that the data fall into two distinct groups: one in which the Idso index recommends irrigation and one in which no irrigation is recommended. The boundary between these two groups can be considered the dynamic critical value of the SDD. Examination of this boundary supports this interpretation. When VPD is high (relative humidity is low), the critical value of the SDD goes as low as -3°C, but when VPD is low (relative humidity is high), SDD goes as high as +2°C. This agrees with energy balance expectations, since transpirational cooling will be highest when VPD is high and lowest when VPD is low. The equation which fits the boundary line is 2.1-1.33*VPD, when VPD is in kPa. This equation is similar to one reported by Pinter and Reginato (1981) for cotton.

Figures 2-3 also show why the Idso index works well as a moisture stress index. The Idso index = (SDD-min)/(3-min) where SDD is the stress degree day, min is the minimum value of SDD expected under well-watered conditions and the constant 3 represents the approximate maximum value of SDD that is expected under water stress conditions when the vapor pressure deficit is very low. As currently calculated, min = 2.67-2.059*VPD. It can be readily seen that the equations for min and the boundary line in figures 2-3 are very similar. Thus, the min function is really the maximum value of SDD under well-watered conditions at a given vapor pressure deficit. Thus, a negative value of the Idso index means that the crop has a temperature well within the range of expected values.

For decision making purposes, the boundary line concept and the Idso technique are similar, though not identical. The boundary line concept says that irrigation is needed whenever SDD rises above the line. The Idso concept says that a certain distance above the boundary line can be tolerated for "practical purposes". In this study, the value of 20% of the distance between the boundary line and the constant 3 was used. This means that the boundary line approach is the more conservative of the two indices.

We are now in a position to evaluate the irrigation scheduling techniques used on the control pivot. Figure 3 shows that the pivot was under stress on 7 days on which irrigation was not recommended using the water balance approach. It also shows that irrigation was recommended on 11 days on which no water stress was evident, indicating that these irrigations could have been delayed one or more days. The temperature techniques and the water balance technique actually agreed on only three irrigation events throughout the season. It is probable that the number of irrigations on the control pivot could have been reduced and/or that the timing of irrigation events could have been significantly altered had the temperature technique been used. This could have resulted in decreased water use or increased grain yield relative to the experimental pivot.

Although the yields and total amount of water used on pivots 38 and 39 was virtually identical (19.3 and 19.1 tons/acre and 15.68 and 15.96 cm, respectively). Figure 3 shows that the reason for this may have been that the control pivot was overirrigated about the same number of times as it was underirrigated.

If the control pivot had been harvested for grain, we believe it would have had a lower grain yield than the experimental pivot, since the control pivot was irrigated late on at least 7 occasions. Unpublished data from the University of Nebraska indicates that there is approximately a 0.7% reduction in grain yield for every day a corn crop experiences a 1°C canopy temperature stress. This projects that the control pivot would have had grain yields approximately 5% less than those on the experimental pivot. Assuming a total yield of 18000 bushels on the experimental pivot, at three dollars per bushel, a 5% reduction in yield would have resulted in a $2700 dollar loss. The reason for this projected loss is based on the belief that the proper timing of irrigation has a major impact on grain yields which is independent of the total amount of water applied.

Jackson Index

The Jackson index is the most theoretically complete of all the indices. This index incorporates solar radiation and windspeed, crop architecture and vapor pressure deficits. Due to its complexity, we will not attempt to detail this index. The explanations in the literature are sufficient. Several researchers who have used this index for detecting moisture stress have indicated they have experienced problems with it. Jackson has stated that his index does not work well in environments having low vapor pressure deficits (private communication).

One of the questions which arises concerning this index is the additional cost of measuring the extra parameters of windspeed and solar radiation. The sensitivity of this index to the accuracy of solar radiation was investigated first. The results (Table 10, Figure 4) show that this equation is very insensitive to the accuracy of solar radiation. When the solar radiation was rounded to the nearest 400 W/M2, the resulting rms error was only 0.02, less than 5% of the value of the mean Jackson index value. In practical terms, this means that an inexpensive silicon cell can be used as an indicator of solar radiation, instead of the expensive thermopile sensors currently being used.

The sensitivity of the Jackson index to windspeed was also investigated (Table 11, Figure 5). The results show that when windspeed is set at a constant 5 miles per hour, the rms error is only 0.05, still an error of less than 10% of the mean index value. This means that windspeed is an unnecessary parameter to measure. Since the prototype will not require a windspeed sensor, there will be an additional (though unspecified) savings in the manufacturing and development of the prototype for the 1985 field experiment.

CTV Index

The CTV index recommended irrigations on four dates when the Idso index did not recommend irrigation. On three of these four dates, the Idso index (when rounded to 1 decimal place) was equal to 0.1 (Table 9). This indicates that when the CTV index recommends irrigation water stress has probably begun. Consequently, the CTV may be more sensitive to water stress that the Idso index. This is not always the case, however. The Idso index recommended irrigation on eight dates when the CTV index did not. On five of these dates, the air temperatures ranged between 30.0 and 35.0°C, the Idso index ranged between 0.24 and 0.51, yet the CTV ranged only between 0.3°C and 0.5°C. The solar radiation on these dates ranged between 676 and 990 W/M2, indicating generally clear skies. This suggests that water stress may develop in a relatively uniform manner in hot, arid environments. On two of the remaining three dates, CTV values were between 0.8 and 0.9, close to the critical value of 1.0 selected for this experiment. The Idso index and the CTV both recommended irrigation on seven dates.

We interpret these results to mean that the CTV index is not suited for use as a primary water stress indicator. It is suited as a "back-up" indicator, however. If the CTV exceeds about 1°C, then the need for irrigation may be indicated. The failure of CTV to exceed 1°C does not mean that stress is not present, especially if the radiation load is high and the air temperature exceeds 30°C. In non-uniform fields, the CTV index may become the primary stress indicator, as shown in the results of the Arkansas study (Keener and Gardner, 1985).

A sensitivity analysis of CTV showed that it is very sensitive to erroneous data values. An erroneous data point which is 9 degrees above or below air temperature would completely destroy the reliability of the CTV as a stress indicator. Erroneous readings of this magnitude are possible if a bare soil temperature reading is accidentally included in the data. Thus, the most effective use of the CTV may be as an indicator of erroneous data rather than moisture stress.

Diff Index

The DIFF index also recommended irrigation on four dates when the Idso index did not. However, on three of these dates, the Idso index was again equal to 0.1 (Table 9). The Idso index recommended irrigation on five dates when the DIFF did not. On these dates, the Idso index ranged between 0.21 and 0.77. The DIFF ranged between 0.2 and 0.5. Air temperatures ranged between 28.0 and 34.5; solar radiation ranged between 750 and 950 W/m2. The Idso and DIFF indices agreed on ten dates.

These results show that when the value of DIFF is greater than 1°C, that irrigation is required. As with the CTV index, however, it is possible for stress to develop without this index detecting it. Thus, the DIFF index is most suited as a back-up index. This finding has important implications for the scheduling of irrigation on center pivots. It means that if the critical value of the Idso is lowered to 0.1, instead of 0.2, that the DIFF index is probably not needed. In practice, this would mean that canopy temperatures would need to be measured only on the dry side of a center pivot. This would result in a simplification of the software needed to process the data and would eliminate potential confusion (and save time) for those who would use this technology on center pivots.

Measurement Resolution

One technical question which has arisen concerns how precisely do we need to measure canopy temperatures? Do we need 0.1°C resolution, or can we obtain the same results with 1°C resolution? In order to evaluate this question, we calculated canopy temperature means and standard deviations two ways. First, the true mean and standard deviation was calculated (0.1°C resolution). Second, the data were rounded to the nearest 1°C and the daily means and standard deviations compared. The results show that 1°C resolution is sufficient to approximate the canopy temperature mean (Figure 6). The accuracy of the standard deviation estimate is strongly affected for standard deviations less than 1.0°C (Figure 7). When the true canopy temperature standard deviation exceeds 1.5°C, the standard deviation of canopy temperature can be estimated closely.

CONCLUSIONS

The data presented here provide further evidence that moisture stress monitoring techniques can be successfully applied to irrigation scheduling in corn. Efforts to commercialize this technology should be made. This study has shown that solar radiation can be measured with inexpensive silicon cells, as compared to expensive thermopile detectors. It has also been shown that windspeed is an unnecessary parameter to measure when evaluating irrigation scheduling indices. The principle irrigation scheduling index is that developed by Idso, with a critical value of around 0.1. The difference in temperature between the wet and dry side of a center pivot is not needed for irrigation scheduling calculations. The variability of canopy temperature measurements is useful as a back-up index, but not as a primary index. The infrared thermometer used to make canopy temperature measurements only needs a resolution of 1°C.

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TABLE 1. Summary of the cultural practices on pivots #38 and #39 at the Thunderbolt Ranch during the 1984 growing season.

	Pivot #38	Pivot #39
Center pivot type	Valley electric	Valley electric
Center pivot length	1485 ft.	1485 ft.
number of towers on pivot	11	11
Planted acres	155	160
Tillage dates	May 15,22,23	May 15,22,23
Tillage type	chisel chopper	chisel chopper
Herbicide	Sutan (3.75 pints) Aatrex-1 quart	Sutan (3.75 pints) Aatrex-1 quart
Planting date	May 23,24	May 24,31
Planter type	24 row Kinze	24 row Kinze
Corn hybrid	Horizon 870 & 871	Horizon 870
Population at emergence	26,700	32.600
Fertilizer (manure)	84.6 tons/acre	71.2 tons/acre
Row Direction	East-West	East-West
Total water applied (cm)	15.68 cm	15.96 cm
Silage yield (tons/acre) (15% moisture)	19.3 tons/acre	19.1 tons/acre

RESTRICTED

TABLE 2. Summary of visual observations made on pivots 38 and 39 at the Thunderbolt Ranch in 1984.

OBS	PIVOT	MONTH	DAY	Canopy height (ft.)	# emerged leaves	leaf condition on wet side of pivot	leaf conditon on dry side of pivot	was pivot on or off ?
1	38	JULY	9	2.5000	9	LITTLE OR NO CURLING	1/4 OF LEAVES CURLED	ON
2	38	JULY	10	3.5000	10	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
3	38	JULY	11	3.5000	10	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
4	38	JULY	12	3.8000	10	LITTLE OR NO CURLING	1/4 OF LEAVES CURLED	OFF
5	38	JULY	13	4.0000	10	3/4 OF LEAVES CURLED	LITTLE OR NO CURLING	ON
6	38	JULY	14	4.0000	10	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
7	38	JULY	15	4.0000	10	LITTLE OR NO CURLING	1/4 OF LEAVES CURLED	OFF
8	38	JULY	16	4.0000	10	1/4 OF LEAVES CURLED	1/2 OF LEAVES CURLED	OFF
9	38	JULY	17	4.5000	12	1/2 OF LEAVES CURLED	1/4 OF LEAVES CURLED	ON
10	38	JULY	18	4.5000	11	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
11	38	JULY	19	4.5000	11	1/2 OF LEAVES CURLED	1/4 OF LEAVES CURLED	ON
12	38	JULY	20	4.5000	11	LITTLE OR NO CURLING	1/4 OF LEAVES CURLED	OFF
13	38	JULY	21	5.0000	11	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
14	38	JULY	22	5.0000	12	1/4 OF LEAVES CURLED	1/4 OF LEAVES CURLED	OFF
15	38	JULY	23	5.0000	12	1/4 OF LEAVES CURLED	LITTLE OR NO CURLING	ON
16	38	JULY	24	5.5000	13	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
17	38	JULY	25	5.5000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
18	38	JULY	26	5.5000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
19	38	JULY	27	5.5000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
20	38	JULY	28	5.6000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
21	38	JULY	29	5.7000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
22	38	JULY	30	5.5000	13	LITTLE OR NO CURLING	1/4 OF LEAVES CURLED	OFF
23	38	JULY	31	6.0000	13	1/4 OF LEAVES CURLED	LITTLE OR NO CURLING	ON
24	38	AUGU	1	6.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
25	38	AUGU	2	6.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
26	38	AUGU	3	6.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
27	38	AUGU	4	6.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
28	38	AUGU	5	6.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
29	38	AUGU	6	6.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
30	38	AUGU	8	6.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
31	38	AUGU	9	6.5000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
32	38	AUGU	10	6.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
33	38	AUGU	11	6.5000	12	LITTLE OR NO CURLING	1/4 OF LEAVES CURLED	OFF
34	38	AUGU	13	.	.	LITTLE OR NO CURLING	1/4 OF LEAVES CURLED	ON
35	38	AUGU	14	8.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
36	38	AUGU	16	12.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
37	38	AUGU	17	.	.	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
38	38	AUGU	18	.	.	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
39	38	AUGU	18	.	.	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
40	38	AUGU	20	6.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
41	38	AUGU	21	7.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
42	38	AUGU	22	7.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
43	38	AUGU	23	7.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
44	38	AUGU	24	7.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
45	38	AUGU	25	7.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
46	38	AUGU	27	7.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
47	38	AUGU	28	7.0000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
48	38	AUGU	29	7.0000	13	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
49	38	AUGU	30	7.0000	13	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
50	38	SEPT	4	7.0000	13	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
51	38	SEPT	5	7.0000	13	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF

Table 2(continued)

OBS	PIVOT	MONTH	DAY	canopy height	# emerged leaves	leaf condition on wet side of pivot	leaf condition on dry side of pivot	was pivot on or off ?
52	39	JULY	9	2.5000	9	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
53	39	JULY	11	3.5000	10	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
54	39	JULY	12	3.5000	9	LITTLE OR NO CURLING	1/4 OF LEAVES CURLED	OFF
55	39	JULY	13	4.00000	10	MOSTLY CURLED	MOSTLY CURLED	ON
56	39	JULY	15	4.00000	10	LITTLE OR NO CURLING	1/4 OF LEAVES CURLED	OFF
57	39	JULY	16	4.00000	10	LITTLE OR NO CURLING	1/4 OF LEAVES CURLED	OFF
58	39	JULY	17	4.50000	12	LITTLE OR NO CURLING	1/4 OF LEAVES CURLED	OFF
59	39	JULY	18	4.50000	11	1/4 OF LEAVES CURLED	LITTLE OR NO CURLING	ON
60	39	JULY	19	4.50000	11	LITTLE OR NO CURLING	1/4 OF LEAVES CURLED	OFF
61	39	JULY	20	4.50000	11	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
62	39	JULY	21	5.00000	11	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
63	39	JULY	23	5.00000	12	1/4 OF LEAVES CURLED	LITTLE OR NO CURLING	ON
64	39	JULY	23	5.00000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
65	39	JULY	26	5.50000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
66	39	JULY	27	5.50000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
67	39	JULY	28	6.00000	13	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
68	39	JULY	29	6.00000	13	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
69	39	JULY	30	5.50000	13	LITTLE OR NO CURLING	1/4 OF LEAVES CURLED	ON
70	39	JULY	31	6.00000	13	1/2 OF LEAVES CURLED	LITTLE OR NO CURLING	ON
71	39	AUGU	1	6.00000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
72	39	AUGU	2	6.00000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
73	39	AUGU	3	6.00000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
74	39	AUGU	4	6.00000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
75	39	AUGU	5	6.00000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
76	39	AUGU	6	6.00000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
77	39	AUGU	8	6.00000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
78	39	AUGU	9	6.50000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
79	39	AUGU	10	6.50000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
80	39	AUGU	11	6.50000	12	LITTLE OR NO CURLING	1/4 OF LEAVES CURLED	ON
81	39	AUGU	13	.	.	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
82	39	AUGU	16	.	.			ON
83	39	AUGU	17	.	.	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
84	39	AUGU	18	7.00000	15	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
85	39	AUGU	18	.	.	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
86	39	AUGU	20	7.00000	15	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
87	39	AUGU	21	7.00000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
88	39	AUGU	23	7.00000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
89	39	AUGU	24	7.00000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
90	39	AUGU	25	7.00000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
91	39	AUGU	27	7.00000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
92	39	AUGU	28	7.00000	12	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
93	39	AUGU	29	7.00000	13	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF
94	39	AUGU	30	7.00000	13	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
95	39	SEPT	4	7.00000	13	LITTLE OR NO CURLING	LITTLE OR NO CURLING	ON
96	39	SEPT	5	7.00000	13	LITTLE OR NO CURLING	LITTLE OR NO CURLING	OFF

TABLE 3. Summary of the environmental conditions and average canopy temperatures for the wet and dry side of pivot #38 at the Thunderbolt Ranch in 1984. Also included is the standard deviation (std) for the dry pivot side canopy temperature measurements.

OBS	MONTH	DAY	RAD (W/M2)	CLOUD COVER (%)	WIND SPEED (M/SEC)	AMBIENT TEMP. (C)	REL. HUM. (%)	WETSIDE TEMP. (C)	DRYSIDE TEMP. (C)	STD DRYSIDE (C)
1	JULY	10	450	100	3.129	21.5	80.7719	24.3	22.8	1.3
2	JULY	11	750	20	2.235	28.0	43.2154	26.9	27.3	0.4
3	JULY	12	920	10	6.705	30.2	38.4598	29.1	29.3	1.1
4	JULY	13	975	10	6.705	34.0	37.4501	33.0	30.4	0.7
5	JULY	14	250	98	6.705	19.5	69.9545	18.9	18.7	0.1
6	JULY	15	945	15	2.235	29.5	43.7801	25.8	26.9	0.8
7	JULY	16	950	50	4.470	31.0	53.1449	30.6	31.1	1.4
8	JULY	17	965	5	3.129	29.5	33.7141	27.1	25.3	0.5
9	JULY	18	965	5	4.470	29.7	45.5607	28.6	30.1	1.1
10	JULY	19	965	10	2.235	34.5	39.2763	30.7	30.2	0.4
11	JULY	20	900	20	2.235	29.5	60.3885	27.8	28.4	0.7
12	JULY	21	290	95	6.705	26.5	61.1519	25.9	26.0	0.2
13	JULY	22	970	2	4.470	31.7	54.2513	31.0	32.0	0.9
14	JULY	23	985	10	2.235	30.5	62.2603	29.0	28.3	0.4
15	JULY	24	320	100	2.235	25.0	66.5961	19.9	20.0	0.8
16	JULY	25	250	100	2.235	24.5	73.2466	23.3	23.2	0.7
17	JULY	26	625	75	4.470	25.5	57.1326	23.0	23.7	0.8
18	JULY	27	980	40	0.894	27.0	32.9358	24.5	24.0	0.6
19	JULY	28	950	20	2.235	28.0	42.1340	25.1	25.1	0.6
20	JULY	29	900	0	6.705	29.0	43.2454	27.3	27.3	2.0
21	JULY	30	845	10	6.705	28.3	50.7347	29.6	30.3	2.1
22	JULY	31	378	95	2.235	28.6	59.1172	30.1	27.0	0.2
23	AUGU	1	900	60	1.341	30.5	55.4630	29.2	29.0	0.6
24	AUGU	2	900	50	0.447	33.0	42.3700	29.5	31.5	1.4
25	AUGU	3	350	100	2.235	25.5	66.9454	24.6	24.5	0.2
26	AUGU	4	970	5	1.341	29.5	55.7713	28.6	30.0	0.8
27	AUGU	5	950	50	0.447	36.0	34.4210	30.4	30.2	0.2
28	AUGU	6	990	5	2.235	35.0	33.3783	29.0	30.6	0.5
29	AUGU	8	990	5	0.447	32.0	34.3793	29.1	30.8	0.5
30	AUGU	9	930	0	2.235	28.0	42.1340	25.5	25.3	0.5
31	AUGU	10	970	0	4.470	30.0	41.7387	25.8	25.9	0.7
32	AUGU	11	900	5	2.235	32.5	41.8772	28.5	30.9	1.1
33	AUGU	13	880	0	2.235	33.0	40.0368	28.4	28.5	0.4
34	AUGU	14	800	0	4.470	32.5	34.9479	28.5	30.6	2.1
35	AUGU	16	870	30	2.235	34.0	38.7789	32.8	30.6	0.6
36	AUGU	17	780	40	4.470	28.6	59.7125	26.3	26.6	0.7
37	AUGU	18	850	0	6.705	28.0	47.6230	25.6	26.2	0.5
38	AUGU	19	700	50	2.235	30.5	42.2717	28.1	28.5	2.1
39	AUGU	20	625	90	2.235	26.0	62.6862	25.7	24.5	0.2
40	AUGU	21	775	10	2.235	29.0	48.6242	25.3	25.3	0.4
41	AUGU	22	800	0	2.235	28.0	42.1340	24.4	24.3	0.3
42	AUGU	23	840	50	4.470	25.5	47.8582	23.3	25.0	0.8
43	AUGU	24	810	80	6.705	26.0	51.4041	25.5	25.6	0.7
44	AUGU	25	675	60	6.705	30.0	49.5759	29.2	31.1	0.4
45	AUGU	27	850	0	0.447	34.5	30.7732	31.4	31.6	0.3
46	AUGU	28	850	10	0.447	35.0	33.3783	31.0	33.0	0.5
47	AUGU	29	850	0	4.470	29.5	31.3133	25.2	26.8	1.5
48	AUGU	30	900	5	2.235	32.5	62.4397	30.3	32.4	0.4
49	SEPT	4	745	0	4.470	24.0	28.4502	19.8	20.8	0.6
50	SEPT	5	790	5	6.705	24.5	37.7487	29.7	26.5	1.0

Table 4. Summary of the environment conditions and average canopy temperatures for the wet and dry side of pivot #39 at the Thunderbolt Ranch in 1984. Also included is the standard deviation (std.) for the dry pivot side canopy temperature measurements.

OBS	MONTH	DAY	RAD (W/M2)	CLOUD COVER (%)	WIND SPEED (M/SEC)	AMBIENT TEMP. (C)	REL. HUM. (%)	WETSIDE TEMP. (C)	DRYSIDE TEMP. (C)	STD DRYSIDE (C)
1	JULY	11	750	40	2.235	28.0	43.2154	25.9	22.9	0.6
2	JULY	12	920	10	6.705	30.2	38.4598	28.2	29.5	0.9
3	JULY	13	975	10	6.705	34.0	37.4501	31.8	31.4	1.7
4	JULY	15	945	20	2.235	29.5	43.7801	26.6	26.5	0.5
5	JULY	16	950	50	4.470	31.0	53.1449	28.7	27.9	0.5
6	JULY	17	965	5	3.129	29.5	33.7141	26.4	25.2	1.2
7	JULY	18	925	5	4.470	29.7	45.5607	31.6	27.8	0.8
8	JULY	19	965	10	2.235	34.5	39.2763	31.1	33.1	3.6
9	JULY	20	900	20	2.235	29.5	60.3885	28.4	28.3	0.5
10	JULY	21	290	95	6.705	26.5	61.1519	25.5	25.6	0.2
11	JULY	22	970	2	4.470	31.7	54.2513	33.3	30.1	0.7
12	JULY	23	985	10	2.235	30.5	62.2603	28.8	28.9	0.4
13	JULY	26	625	75	4.470	25.5	57.1326	21.3	21.2	0.1
14	JULY	27	980	40	0.894	26.0	36.9431	24.4	24.3	0.4
15	JULY	28	950	20	2.235	28.0	42.1340	21.3	23.1	0.5
16	JULY	29	900	0	6.705	29.0	43.2454	27.7	27.1	0.5
17	JULY	30	938	10	6.705	28.3	50.7347	32.6	27.0	0.8
18	JULY	31	725	95	4.470	28.8	58.0934	30.6	27.1	1.0
19	AUGU	1	900	60	1.341	30.5	55.4630	28.0	28.9	0.7
20	AUGU	2	900	60	0.447	33.0	42.3700	29.0	27.7	0.6
21	AUGU	3	350	100	2.235	25.5	66.9454	24.3	24.6	0.3
22	AUGU	4	970	5	1.341	29.5	55.7713	28.5	28.4	0.6
23	AUGU	5	950	50	0.447	36.0	34.4210	29.8	30.1	0.9
24	AUGU	6	990	5	2.235	35.0	33.3783	32.7	31.2	0.8
25	AUGU	8	990	5	0.447	32.0	34.3793	29.5	30.8	0.4
26	AUGU	9	930	0	2.235	28.0	42.1340	25.0	25.4	0.2
27	AUGU	10	970	0	4.470	30.0	41.7387	25.8	25.4	0.3
28	AUGU	11	900	5	2.235	32.5	41.8772	31.2	29.1	0.2
29	AUGU	13	880	0	2.235	33.0	40.0368	28.5	28.5	0.3
30	AUGU	14	800	0	4.470	32.5	34.9479	26.8	28.3	0.3
31	AUGU	16	870	30	2.235	34.0	38.7789	30.2	30.1	0.7
32	AUGU	17	770	40	4.470	28.6	59.7125	26.3	26.0	0.3
33	AUGU	18	850	0	6.705	28.0	47.6230	25.8	26.0	0.7
34	AUGU	20	625	90	2.235	26.0	62.0391	26.7	26.5	0.5
35	AUGU	21	775	10	2.235	29.0	48.6242	25.1	25.2	0.5
36	AUGU	22	800	0	2.235	28.0	42.1340	24.3	24.3	0.3
37	AUGU	23	840	50	4.470	25.5	47.8582	25.1	24.2	0.8
38	AUGU	24	810	80	6.705	26.0	51.4041	25.9	25.6	0.9
39	AUGU	25	675	60	6.705	30.0	49.5759	30.3	30.4	0.6
40	AUGU	27	850	0	0.447	34.5	30.7732	33.2	31.6	0.3
41	AUGU	28	850	10	0.447	34.5	34.9431	31.4	32.5	0.5
42	AUGU	29	850	0	4.470	29.5	31.3133	26.4	27.7	1.6
43	AUGU	30	900	5	2.235	32.5	62.4397	31.2	33.3	0.4
44	SEPT	4	745	0	4.470	24.0	28.4502	19.4	20.4	0.3
45	SEPT	5	790	5	6.705	24.5	37.7487	29.2	26.7	0.6

Table 5. Mean values of five irrigation scheduling indices for pivot 38 at the Thunderbolt Ranch in 1984. SDD=stress degree day Idso= index develop by S.B. Idso Jkson= index developed by R. Jackson Diff= difference between the dry side and the wet side of the pivot diff=(dry-wet) std= standard deviation of temperature measurements on the dry side of the pivot.

OBS	MONTH	DAY	SDD	IDSO	JKSON	DIFF	STD
1	JULY	10	1.3	-0.2638	1.33771	-1.5	1.3
2	JULY	11	-0.7	0.2209	0.75841	0.4	0.4
3	JULY	12	-0.9	0.3238	0.80848	0.2	1.1
4	JULY	13	-3.6	0.0808	0.51849	-2.6	0.7
5	JULY	14	-0.8	-1.1937	0.67153	-0.2	0.1
6	JULY	15	-2.6	-0.0976	0.49167	1.1	0.8
7	JULY	16	0.1	0.3782	0.87572	0.5	1.4
8	JULY	17	-4.2	-0.2088	0.39935	-1.8	0.5
9	JULY	18	0.4	0.4805	0.92803	1.5	1.1
10	JULY	19	-4.3	-0.0185	0.38358	-0.5	0.4
11	JULY	20	-1.1	-0.1104	0.57932	0.6	0.7
12	JULY	21	-0.5	-0.1294	0.84637	0.1	0.2
13	JULY	22	0.3	0.4295	0.90229	1.0	0.9
14	JULY	23	-2.2	-0.3969	0.36472	-0.7	0.4
15	JULY	24	-5.0	-2.1891	-0.36921	0.1	0.8
16	JULY	25	-1.3	-1.1250	0.47177	-0.1	0.7
17	JULY	26	-1.8	-0.4953	0.53816	0.7	0.8
18	JULY	27	-3.0	-0.1423	0.44167	-0.5	0.6
19	JULY	28	-2.9	-0.2207	0.44985	0.0	0.6
20	JULY	29	-1.7	0.0620	0.68075	0.0	2.0
21	JULY	30	2.0	0.7637	1.22270	0.7	2.1
22	JULY	31	-1.6	-0.2692	0.59239	-3.1	0.2
23	AUGU	1	-1.5	-0.0384	0.52694	-0.2	0.6
24	AUGU	2	-1.5	0.2855	0.58312	2.0	1.4
25	AUGU	3	-1.0	-0.5681	0.62463	-0.1	0.2
26	AUGU	4	0.5	0.3879	0.79944	1.4	0.8
27	AUGU	5	-5.8	-0.0538	0.24801	-0.2	0.2
28	AUGU	6	-4.4	0.0798	0.42541	1.6	0.5
29	AUGU	8	-1.2	0.3781	0.63079	1.7	0.5
30	AUGU	9	-2.7	-0.1793	0.47781	-0.2	0.5
31	AUGU	10	-4.1	-0.3101	0.36120	0.1	0.7
32	AUGU	11	-1.6	0.2560	0.65578	2.4	1.1
33	AUGU	13	-4.5	-0.1468	0.34443	0.1	0.4
34	AUGU	14	-1.9	0.2878	0.70450	2.1	2.1
35	AUGU	16	-3.4	0.0902	0.48844	-2.2	0.6
36	AUGU	17	-2.1	-0.3980	0.48732	0.3	0.7
37	AUGU	18	-1.8	-0.0894	0.63737	0.6	0.5
38	AUGU	19	-2.1	0.0941	0.61818	0.4	2.1
39	AUGU	20	-1.5	-0.5452	0.49951	-1.2	0.2
40	AUGU	21	-3.7	-0.4671	0.31024	0.0	0.4
41	AUGU	22	-3.7	-0.3862	0.36358	-0.1	0.3
42	AUGU	23	-0.5	0.0869	0.79577	1.7	0.8
43	AUGU	24	-0.4	0.0794	0.83505	0.1	0.7
44	AUGU	25	1.1	0.5987	1.09397	1.9	0.4
45	AUGU	27	-2.9	0.2738	0.53354	0.2	0.3
46	AUGU	28	-2.1	0.3783	0.60507	2.0	0.5
47	AUGU	29	-2.7	0.0747	0.60885	1.6	1.5
48	AUGU	30	-0.1	0.2461	0.75346	2.1	0.4
49	SEPT	4	-3.2	-0.3120	0.52119	1.0	0.6
50	SEPT	5	2.0	0.7658	1.20265	-3.2	1.0

Table 6. Mean values of five irrigation scheduling indices for pivot 39 at the Thunderbolt Ranch in 1984. SDD= stress degree day Idso= index developed by S.B. Idso Jkson=index developed by R. Jackson Diff= mean difference between the dry side and the wet side of the pivot diff= (dry-wet) std=standard deviation of the canopy temperatures from the dry side of the pivot.

OBS	MONTH	DAY	SDD	IDSO	JKSON	DIFF	STD
1	JULY	9	-1.6	-0.5186	0.43471	0.0	1.0
2	JULY	11	-5.1	-0.7056	0.17148	-3.0	0.6
3	JULY	12	-0.7	0.3585	0.83310	1.3	0.9
4	JULY	13	-2.6	0.2200	0.63035	-0.4	1.7
5	JULY	15	-3.0	-0.1760	0.44093	-0.1	0.5
6	JULY	16	-3.1	-0.3080	0.39031	-0.8	0.5
7	JULY	17	-4.3	-0.2256	0.38818	-1.2	1.2
8	JULY	18	-1.9	0.0209	0.61929	-3.8	0.8
9	JULY	19	-1.4	0.3861	0.69380	2.0	3.6
10	JULY	20	-1.2	-0.1375	0.56208	-0.1	0.5
11	JULY	21	-0.9	-0.2585	0.75910	0.1	0.2
12	JULY	22	-1.6	0.0281	0.61262	-3.2	0.7
13	JULY	23	-1.6	-0.2357	0.46853	0.1	0.4
14	JULY	26	-4.3	-1.2741	0.05576	-0.1	0.1
15	JULY	27	-1.7	-0.0013	0.55099	-0.1	0.4
16	JULY	28	-4.9	-0.6345	0.19440	1.8	0.5
17	JULY	29	-1.9	0.0220	0.65345	-0.6	0.5
18	JULY	30	-1.3	-0.0162	0.69011	-5.6	0.8
19	JULY	31	-1.7	-0.2546	0.56771	-3.5	1.0
20	AUGU	1	-1.6	-0.0615	0.51226	0.9	0.7
21	AUGU	2	-5.3	-0.3178	0.17814	-1.3	0.6
22	AUGU	3	-0.9	-0.5289	0.64942	0.3	0.3
23	AUGU	4	-1.1	-0.0039	0.56155	-0.1	0.6
24	AUGU	5	-5.9	-0.0657	0.23903	0.3	0.9
25	AUGU	6	-3.8	0.1544	0.48381	-1.5	0.8
26	AUGU	8	-1.2	0.3781	0.63079	1.3	0.4
27	AUGU	9	-2.6	-0.1587	0.49062	0.4	0.2
28	AUGU	10	-4.6	-0.4024	0.29777	-0.4	0.3
29	AUGU	11	-3.4	-0.0352	0.44605	-2.1	0.2
30	AUGU	13	-4.5	-0.1468	0.34443	0.0	0.3
31	AUGU	14	-4.2	-0.0465	0.45072	1.5	0.3
32	AUGU	16	-3.9	0.0191	0.43420	-0.1	0.7
33	AUGU	17	-2.6	-0.5658	0.37642	-0.3	0.3
34	AUGU	18	-2.0	-0.1348	0.60717	0.2	0.7
35	AUGU	20	0.5	0.1546	0.91450	-0.2	0.5
36	AUGU	21	-3.8	-0.4890	0.29602	0.1	0.5
37	AUGU	22	-3.7	-0.3862	0.36358	0.0	0.3
38	AUGU	23	-1.3	-0.1218	0.66987	-0.9	0.8
39	AUGU	24	-0.4	0.0794	0.83505	-0.3	0.9
40	AUGU	25	0.4	0.4509	0.98772	0.1	0.6
41	AUGU	27	-2.9	0.2738	0.53354	-1.6	0.3
42	AUGU	28	-2.0	0.3469	0.59376	1.1	0.5
43	AUGU	29	-1.8	0.2208	0.70891	1.3	1.8
44	AUGU	30	0.8	0.4650	0.90604	2.1	0.4
45	SEPT	4	-3.6	-0.3967	0.47213	1.0	0.3
46	SEPT	5	2.2	0.8127	1.23065	-2.5	0.6

TABLE 7. Irrigation (I) and rainfall (R) amounts at Thunderbolt Ranch for pivot #38 between July 1 and September 14,1984. Assumed efficiency of application is also indicated.

	DATE	DAY OF YEAR	AMOUNT (inches)	ASSUMED EFFICIENCY (%)	EFFECTIVE AMOUNT APPLIED (inches)
(R)	2 July	183	0.11	55	0.06
(R)	5 July	186	0.15	55	0.08
(R)	9 July	190	0.47	55	0.26
(I)	13 July	194	0.49	80	0.39
(I)	17 July	198	0.63	80	0.50
(I+R)	19 July	200	1.17	50	0.59
(I)	23 July	204	0.67	80	0.54
(R)	25 July	206	0.92	70	0.64
(I)	31 July	212	0.77	80	0.62
(R)	2 August	214	0.25	70	0.18
(I)	3 August	215	0.80	80	0.64
(I)	5 August	217	0.74	80	0.59
(R)	7 August	219	0.32	70	0.22
(I)	9 August	221	0.76	80	0.61
(I)	12 August	224	0.76	80	0.61
(I)	15 August	227	0.76	80	0.61
(R)	20 August	232	1.90	55	1.05
(I)	24 August	236	0.77	80	0.62
(I)	27 August	239	0.83	80	0.66
(I)	3 September	246	0.98	80	0.78
(I)	8 September	251	0.83	80	0.66
(R)	11 September	254	0.30	80	0.24
(R)	14 September	257	0.30	80	0.24
			15.68		11.63

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TABLE 8. Irrigation (I) and rainfall (R) amounts for Thunderbolt Ranch for pivot #39 between July 1 and September 14,1984. Assumed efficiency of application is also indicated.

	DATE	DAY OF YEAR	AMOUNT (inches)	ASSUMED EFFICIENCY (%)	EFFECTIVE AMOUNT APPLIED (inches)
(R)	2 July	183	0.11	55	0.06
(R)	5 July	186	0.15	55	0.08
(I)	6 July	187	0.62	80	0.50
(R)	9 July	190	0.47	55	0.26
(I)	10 July	191	0.60	80	0.48
(I)	14 July	195	0.70	80	0.56
(I)	18 July	199	0.64	80	0.51
(I)	19 July	200	0.43	55	0.24
(I)	21 July	202	0.72	80	0.58
(I+R)	25 July	206	1.64	70	1.15
(I)	30 July	211	0.68	80	0.54
(I+R)	2 August	214	1.02	70	0.71
(I+R)	7 August	219	0.98	77	0.75
(I)	13 August	225	0.75	80	0.60
(I)	16 August	228	0.75	80	0.60
(I+R)	20 August	232	2.66	62	1.65
(I)	29 August	241	0.80	80	0.64
(I)	1 September	244	0.80	80	0.64
(I)	4 September	247	0.84	80	0.67
(R)	11 September	254	0.30	80	0.24
(R)	14 September	257	0.30	80	0.24
			15.96		12.21

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TABLE 9. Summary of the irrigation scheduling recommendations made by several water stress indices. An asterisk indicateds the days on which the decision to irrigate was made.

OBS	MONTH	DAY	DAY OF YEAR	AIR TEMP. (C)	CLOUD COVER (%)	SOLAR RAD. (W/M2)	JACKSON REC.	JACKSON INDEX VALUE	IDSO REC.	IDSO INDEX VALUE	SDD REC.	SDD INDEX VALUE	CTV REC.	CTV INDEX VALUE	DIFF REC.	DIFF INDEX VALUE
1	JULY	10	191	21.5	100	450	IRR	1.34	NO	-0.27	IRR	1.3	IRR	1.3	NO	-1.5
2	JULY	11	192	28.0	20	750	IRR	0.75	IRR	0.21	IRR	-0.7	NO	0.4	NO	0.4
* 3	JULY	12	193	30.2	10	920	IRR	0.81	IRR	0.33	IRR	-0.9	IRR	1.1	NO	0.2
4	JULY	13	194	34.0	10	975	NO	0.51	NO	0.07	NO	-3.6	NO	0.7	NO	-2.6
5	JULY	14	195	19.5	98	250	NO	0.67	NO	-1.20	IRR	-0.8	NO	0.1	NO	-0.2
6	JULY	15	196	29.5	15	945	NO	0.49	NO	-0.10	NO	-2.6	NO	0.8	IRR	1.0
* 7	JULY	16	197	31.0	50	950	IRR	0.88	IRR	0.38	IRR	0.1	IRR	1.4	NO	0.5
8	JULY	17	198	29.5	5	965	NO	0.40	NO	-0.20	NO	-4.2	NO	0.5	NO	-1.8
* 9	JULY	18	199	29.7	5	965	IRR	0.93	IRR	0.49	IRR	0.4	IRR	1.1	IRR	1.5
10	JULY	19	200	34.5	10	965	NO	0.38	NO	-0.02	NO	-4.3	NO	0.4	NO	-0.5
11	JULY	20	201	29.5	20	900	NO	0.59	NO	-0.10	IRR	-1.1	NO	0.7	NO	0.6
12	JULY	21	202	26.5	95	290	IRR	0.84	NO	-0.14	IRR	-0.5	NO	0.2	NO	0.1
*13	JULY	22	203	31.7	2	970	IRR	0.91	IRR	0.44	IRR	0.3	NO	0.9	IRR	1.0
14	JULY	23	204	30.5	10	985	NO	0.37	NO	-0.38	NO	-2.2	NO	0.4	NO	-0.6
15	JULY	24	205	25.0	100	320	NO	-0.36	NO	-2.20	NO	-5.0	NO	0.8	NO	0.1
16	JULY	25	206	24.5	100	250	NO	0.47	NO	-1.10	IRR	-1.3	NO	0.7	NO	-0.2
17	JULY	26	207	25.5	75	625	NO	0.55	NO	-0.48	IRR	-1.8	NO	0.8	NO	0.7
18	JULY	27	208	27.0	40	980	NO	0.44	NO	-0.14	NO	-3.0	NO	0.6	NO	-0.5
19	JULY	28	209	28.0	20	950	NO	0.46	NO	-0.21	NO	-2.9	NO	0.6	NO	0.0
20	JULY	29	210	29.0	0	900	NO	0.69	NO	0.07	IRR	-1.7	IRR	2.0	NO	0.0
*21	JULY	30	211	28.3	10	845	IRR	1.22	IRR	0.77	IRR	2.0	IRR	2.1	NO	0.7
22	JULY	31	212	28.6	95	378	NO	0.60	NO	-0.26	IRR	-1.6	NO	0.2	NO	-3.1
23	AUGU	1	213	30.5	60	900	NO	0.53	NO	-0.03	IRR	-1.5	NO	0.6	NO	-0.1
*24	AUGU	2	214	33.0	50	900	NO	0.58	IRR	0.28	IRR	-1.5	IRR	1.4	IRR	2.0
25	AUGU	3	215	25.5	100	350	NO	0.62	NO	-0.58	IRR	-1.0	NO	0.2	NO	-0.1
*26	AUGU	4	216	29.5	5	970	IRR	0.80	IRR	0.39	IRR	0.5	NO	0.8	IRR	1.4
27	AUGU	5	217	36.0	50	950	NO	0.25	NO	-0.05	NO	-5.8	NO	0.2	NO	-0.2
28	AUGU	6	218	35.0	5	990	NO	0.42	NO	0.08	NO	-4.4	NO	0.5	IRR	1.6
*29	AUGU	8	220	32.0	5	990	NO	0.63	IRR	0.37	IRR	-1.2	NO	0.5	IRR	1.7
30	AUGU	9	221	28.0	0	930	NO	0.48	NO	-0.18	NO	-2.7	NO	0.5	NO	-0.2
31	AUGU	10	222	30.0	0	970	NO	0.37	NO	-0.30	NO	-4.1	NO	0.7	NO	0.2
*32	AUGU	11	223	32.5	5	900	NO	0.65	IRR	0.25	IRR	-1.6	IRR	1.1	IRR	2.4
33	AUGU	13	225	33.0	0	880	NO	0.35	NO	-0.14	NO	-4.5	NO	0.4	NO	0.1
*34	AUGU	14	226	32.5	0	800	IRR	0.71	IRR	0.29	IRR	-1.9	IRR	2.1	IRR	2.1
35	AUGU	16	228	34.0	30	870	NO	0.49	NO	0.09	NO	-3.4	NO	0.6	NO	-2.2
36	AUGU	17	229	28.6	40	780	NO	0.48	NO	-0.41	NO	-2.1	NO	0.7	NO	0.2
37	AUGU	18	230	28.0	0	850	NO	0.64	NO	-0.09	IRR	-1.8	NO	0.5	NO	0.6
*38	AUGU	19	231	30.5	50	700	NO	0.61	NO	0.09	NO	-2.0	IRR	2.1	NO	0.4
39	AUGU	20	232	26.0	90	625	NO	0.49	NO	-0.56	IRR	-1.5	NO	0.2	NO	-1.2
40	AUGU	21	233	29.0	10	775	NO	0.32	NO	-0.46	NO	-3.7	NO	0.4	NO	0.1
41	AUGU	22	234	28.0	0	800	NO	0.36	NO	-0.39	NO	-3.7	NO	0.3	NO	-0.1
*42	AUGU	23	235	25.5	50	840	IRR	0.79	NO	0.08	IRR	-0.5	NO	0.8	IRR	1.7
43	AUGU	24	236	26.0	80	810	IRR	0.83	NO	0.07	IRR	-0.4	NO	0.7	NO	0.1
*44	AUGU	25	237	30.0	60	675	IRR	1.09	IRR	0.59	IRR	1.1	NO	0.4	IRR	1.8
45	AUGU	27	239	34.5	0	850	NO	0.53	IRR	0.27	NO	-2.9	NO	0.3	NO	0.2
46	AUGU	28	240	35.0	10	850	NO	0.60	IRR	0.37	NO	-2.1	NO	0.5	IRR	1.9
47	AUGU	29	241	29.5	0	850	NO	0.60	NO	0.07	NO	-2.8	IRR	1.5	IRR	1.6
*48	AUGU	30	242	32.5	5	900	IRR	0.75	IRR	0.24	IRR	-0.1	NO	0.4	IRR	2.1
49	SEPT	4	247	24.0	0	745	NO	0.52	NO	-0.32	NO	-3.2	NO	0.6	NO	0.9

Table 10. Statistical analysis of the data in figure 4, showing the relationship between the actual value of the Jackson equation, using the data from pivot 38, versus the calculated value when radiation was rounded to the nearest 400 W/M2.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: JACKSON PREDICTION (True value)

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	3.71030974	3.71030974	6535.05	0.0001	0.992709	3.8898
ERROR	48	0.02725226	0.00056776		ROOT MSE		JKSON MEAN
CORRECTED TOTAL	49	3.73756200			0.02382762		0.61260000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
JACKSON PREDICTION (Radiation rounded to nearest 400 W/M2)	1	3.71030974	6535.05	0.0001	1	3.71030974	6535.05	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	0.00761674	0.93	0.3580	0.00820741
ACKSON PREDICTION Radiation rounded to earest 400 W/M2)	0.99885681	80.84	0.0001	0.01235603

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Table 11. Statistical analysis of the data in figure 5, showing the relationship between the actual value of the Jackson equation, using the data from pivot 38, versus the calculated value when windspeed was held at a constant 5 miles per hour.

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: JACKSON (true value)

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	3.64104354	3.64104354	1810.74	0.0001	0.974176	7.3199
ERROR	48	0.09651846	0.00201080		ROOT MSE		JKSON MEAN
CORRECTED TOTAL	49	3.73756200			0.04484196		0.61260000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
JACKSON PREDICTION windspeed set at 5 miles per hour)	1	3.64104354	1810.74	0.0001	1	3.64104354	1810.74	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-0.02109048	-1.30	0.1988	0.01618590
JACKSON PREDICTION Windspeed set at 5 miles per hour)	1.06169440	42.55	0.0001	0.02495003

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Figure 1. Seasonal pattern of the Idso index on pivot 38.

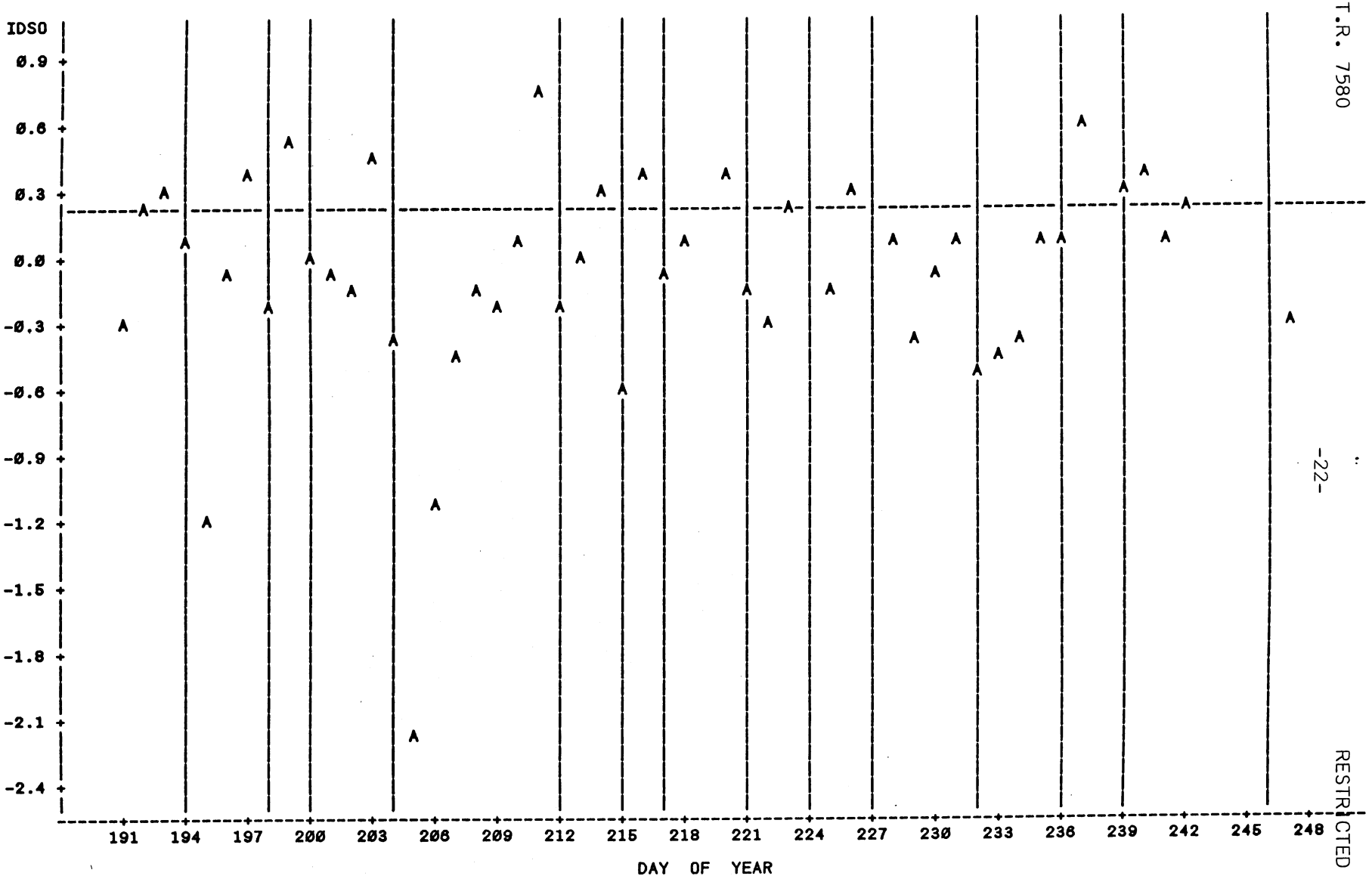

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FIGURE 2. Relationship between the SDD index and vapor pressure deficits (kPa). The asterisks separate data collected on days on which irrigation was and was not required on pivot 38. A Y indicates Idso's index recommended irrigation. An N indicates Idso's index did not recommend irrigation.

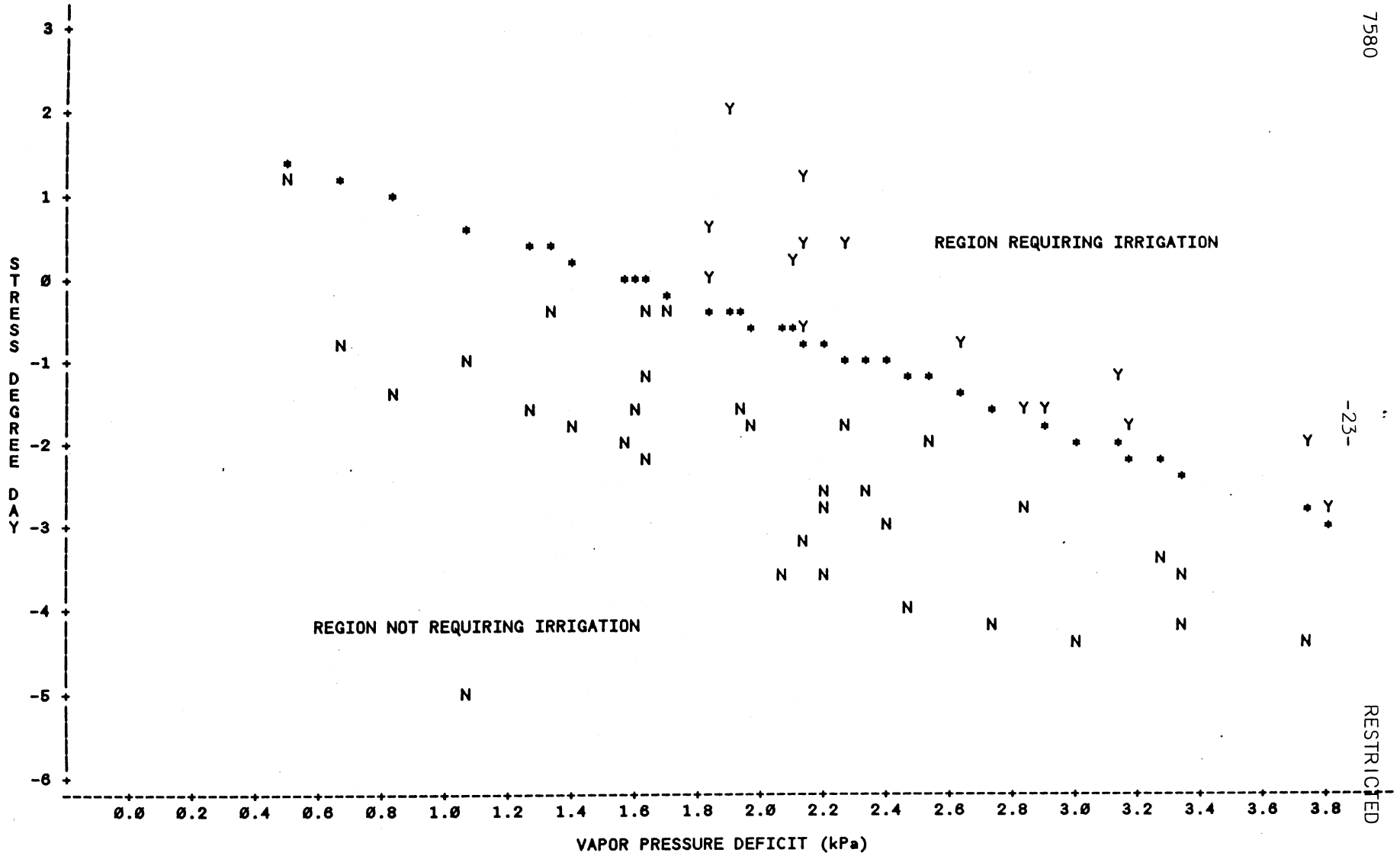

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FIGURE 3. Relationship between the SDD index and vapor pressure deficits (kPa). The asterisks separate data collected on days on which irrigation was scheduled by an independent water balance technique on pivot 39. A Y indicates irrigation was actually scheduled using the water balance approach. An N indicates the irrigation system was not turned on.

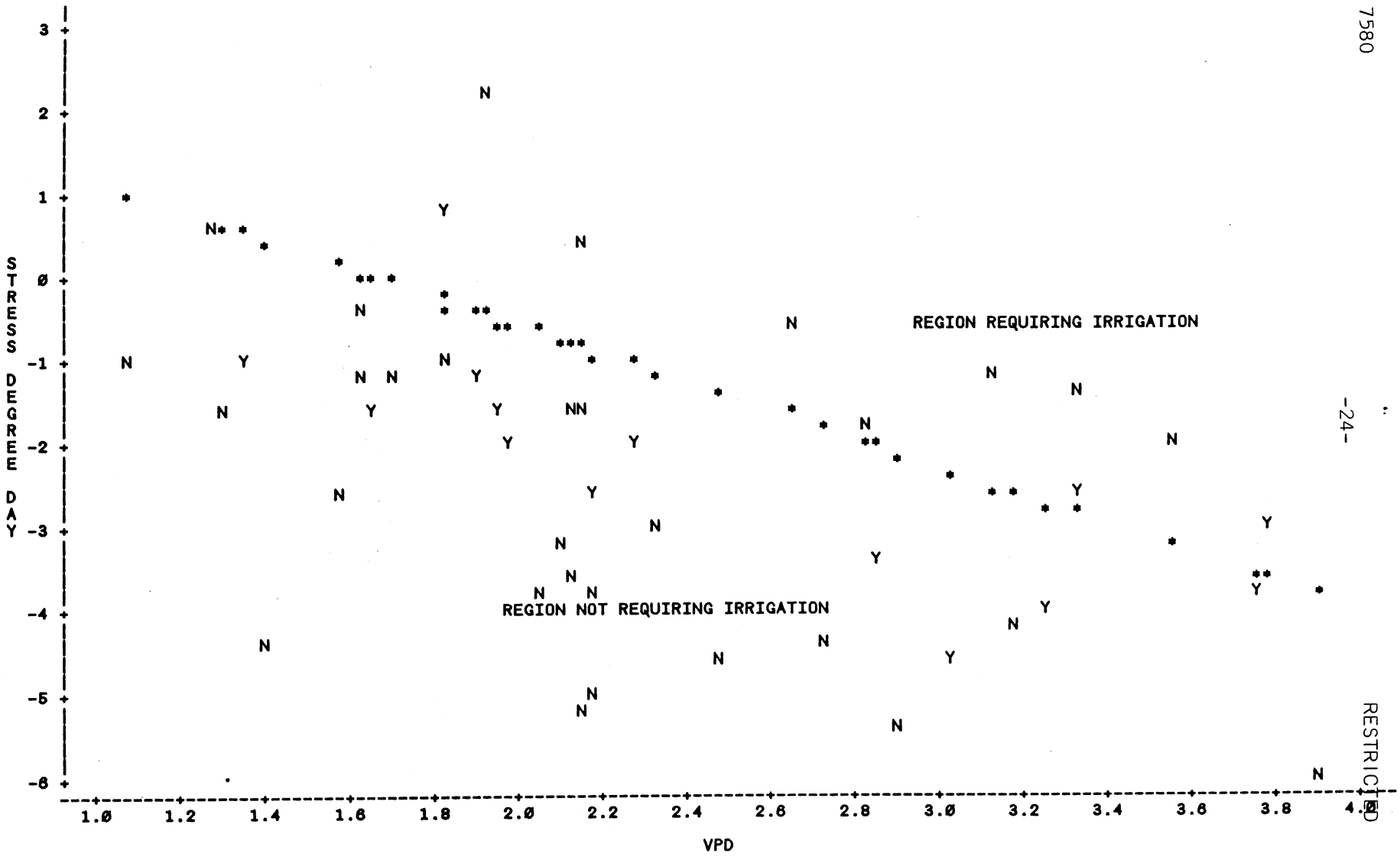

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Figure 4. Jackson equation --actual value versus calculated value assuming solar radiation has been rounded to the nearest 400 W/M2. The comparison was performed using the data from pivot 38. An asterisk indicates the 1:1 line.

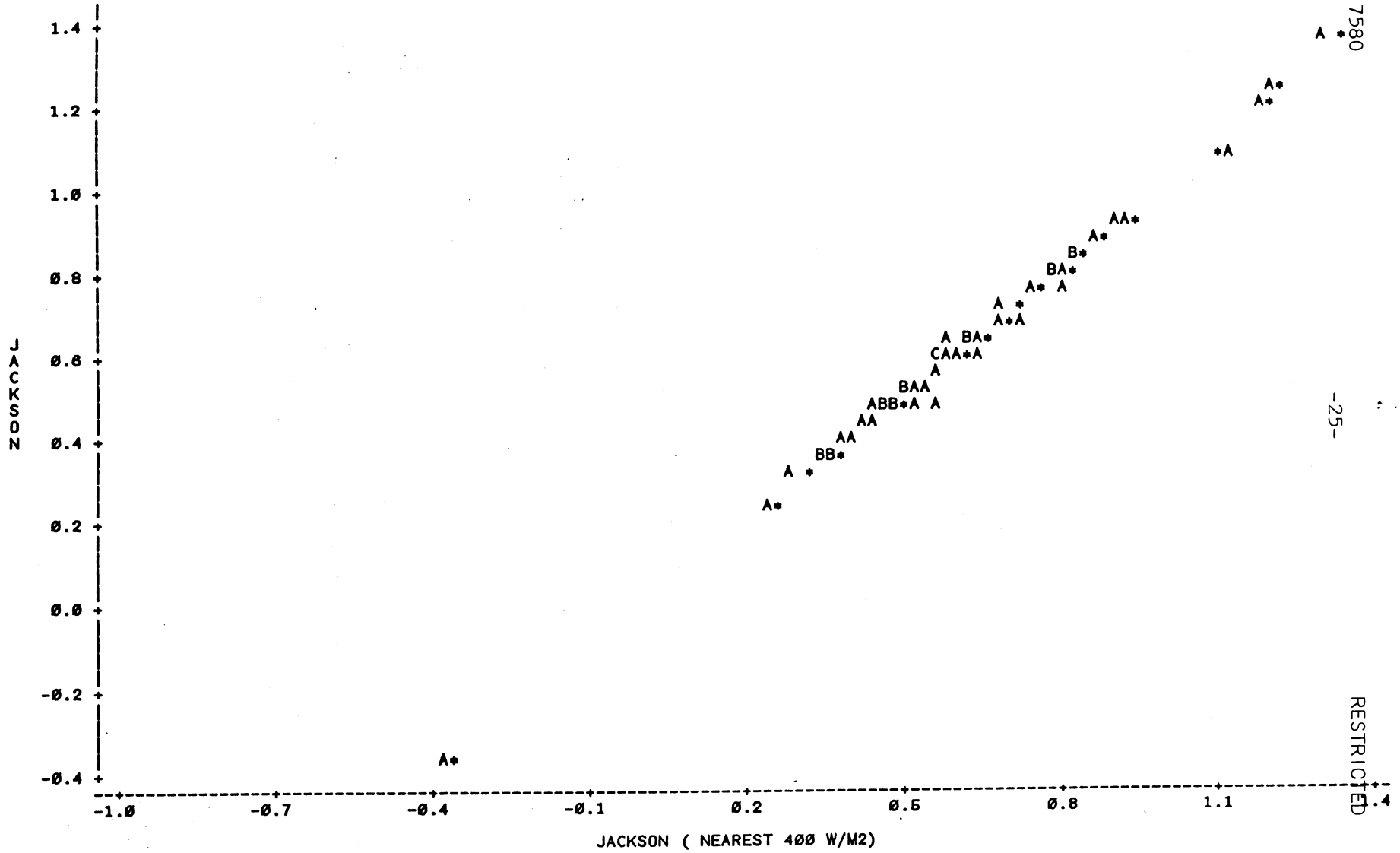

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Figure 5. Jackson equation--actual value versus calculated value assuming windspeed has been set at a constant 5 miles per hour. An asterisk indicates the 1:1 line.

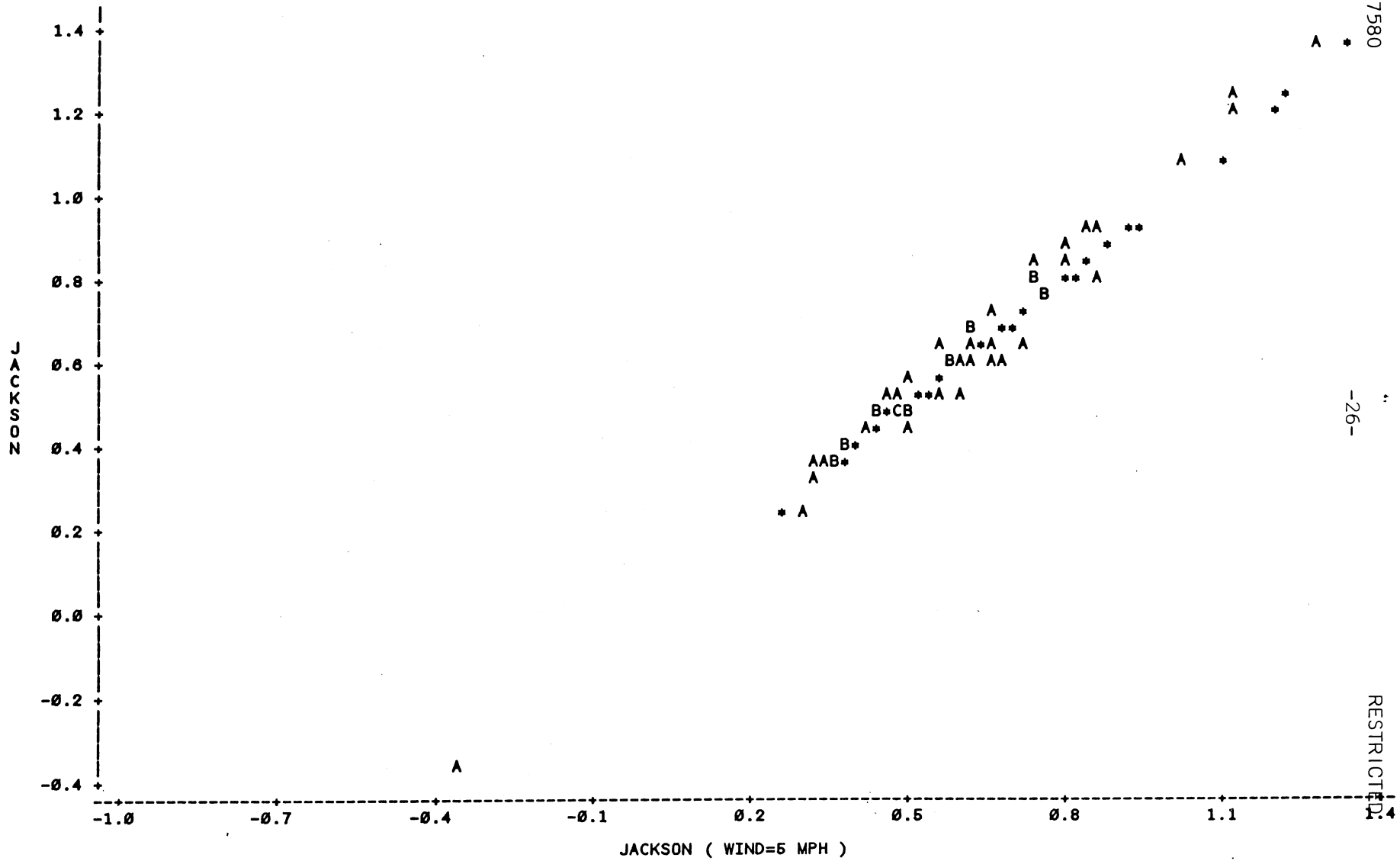

Figure 6. Comparison between canopy temperature means using Ø.1 C resolution (true means) and 1 C resolution (rounded means) for data from pivot 38.

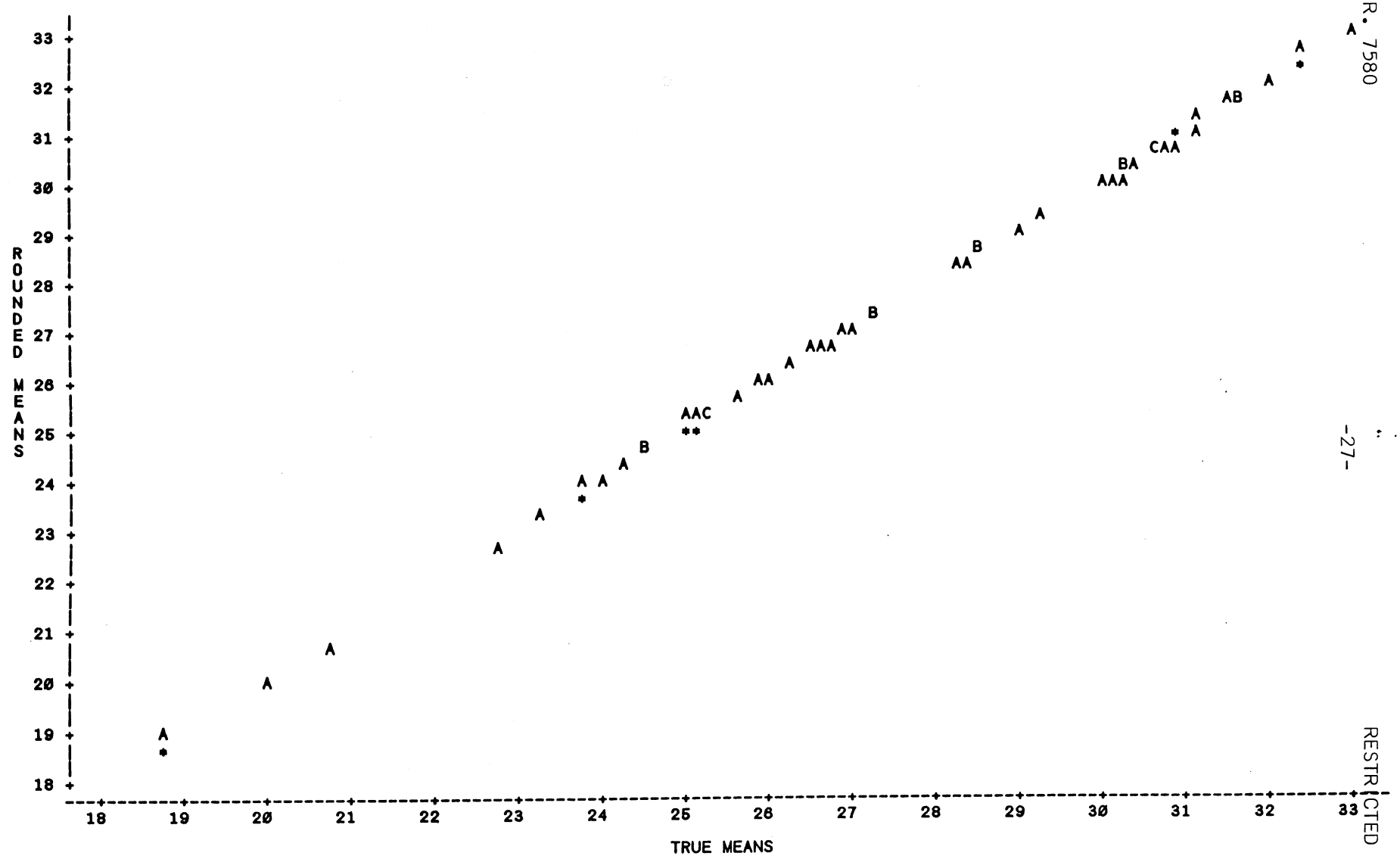

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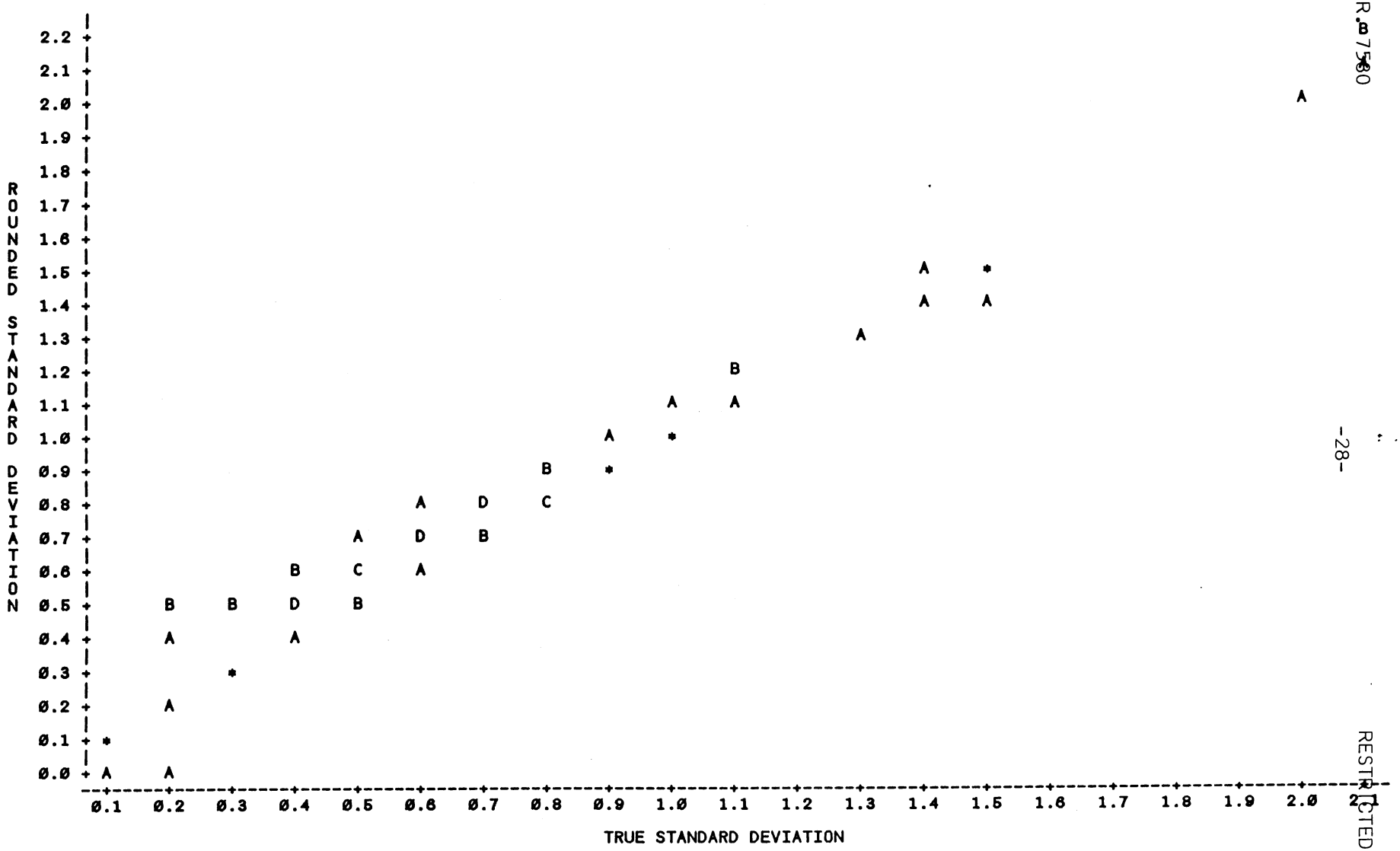
Figure 7. Standard deviations for canopy temperature means on pivot 38 using 0.1 C resolution (true standard deviation) and 1 C resolution (rounded standard deviation).



T.R. 7560

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STANDARD OIL
ENGINEERED MATERIALS

Memorandum

To: All Scheduler^{R} Personnel

Date: 9/8/87

From: C. A. Fiorina CAF

Copy to:

Subject: SCHEDULER^{R} SOFTWARE UPDATE

SS0013	Production/Ag
SS1009	Turf
SS2010	R&D
SS4001	R&D Polycorder version
DS0013	Diagnostic

The only software change has been the addition of the 4000 series. SS4001 is an R&D version with enhancements to work with a polycorder. Bronson has designed a program to handle the data sent out to the polycorder.

CAF/lb

STANDARD OIL
ENGINEERED MATERIALS

Memorandum

To: J. K. Riley

Date: 11/24/87

From: B. R. Gardner

Copy to:

Subject: DATA REQUIREMENTS FOR BASELINE DETERMINATIONS

1. Description of aiming technique. The technique must insure that the vast majority of vegetation in the field of view is sunlit. Shadows measured must be minimal. We should be responsible for defining the aiming technique.

2. Dates of rainfall and irrigation. Without these, interpretation of trends is difficult.

3. Yield and/or quality data. This allows us to determine if the patterns presented are representative of normal and below normal agronomic results.

4. A comparison area, i.e., an area which has a much lower yield than normal (less than 1/2 of normal). Irrigations, rainfall dates, yield/quality and Scheduler^{R} Plant Stress Monitor data from this area are also needed. The area does not need to be large.

5. Transfer of the data in the ACSII format to Standard Oil Engineered Materials Company on 5 1/4 inch diskettes. All data should be clearly documented.

6. An agronomic description of the life cycle of the crop:

   a. When the season begins.

   b. How the crop changes in physical appearance through the season.

   c. When harvest occurs.

   d. If a perennial crop, the importance of post-harvest treatments to the following year's crop.

   e. Factors which are known to affect the yield and quality of the crop. For example, sensitivities to particular nutrients or cultural practices.

   f. Critical time periods in crop/yield development.

7. A description of the cultural practices used. Are these practices representative of the industry? Are these industry standards or accepted practices?

8. Scheduler data should be obtained three times weekly (Monday, Wednesday, Friday) at a minimum.

9. Care must be taken to take data during optimal conditions as much as possible.

BRG/lb

Standard Oil
Engineered Materials Company
Sensor Technologies
P.O. Box 391316
6180 Cochran Road
Solon, Ohio 44139
216 349-6881

April 21, 1988

STANDARD OIL
ENGINEERED MATERIALS
SENSOR TECHNOLOGIES

Dr. D. J. Westlake
BP Ventures
Britanica House
London
England

Dear Dr. Westlake:

Dave Dunn has asked me to respond to the question of how the Scheduler^{R} Plant Stress Monitor might be used on pipelines to measure temperature gradients. My understanding of the problem is that temperature gradients may be associated with the development of corrosion.

The Scheduler infrared thermometer and computer package are well-suited for this type of application. The current software is not tailored for the problem, but could be used. I can envision at least two possible ways to use the instrument.

One method would be to use the standard deviation of surface temperature as an index of temperature uniformity along a given section of pipe. The Scheduler currently can sample a maximum of 55 readings spaced 1/4 second apart. Standard deviations outside of "normal" would flag a problem area. The number of samples and length of pipe for a given sample would need to be determined.

Another mode of operation would be to use the pipe temperature at one location as a reference. Deviations from this temperature could then be displayed on the bar-graph on the back of the gun, thus providing a visual indication of whether or not a spot is relatively hot or cold. This number could also be permanently stored and displayed. Custom software would be needed for this application.

A third mode of operation is to analyze absolute temperatures suggesting temperature as an analysis mode. The absolute accuracy of an infrared thermometer depends on the emissivity of the surface being viewed. My concern is that emissivities on various sections of the pipe may not be uniform. Factors which may alter the emissivity include type, age, and surface conditions of the material.

In addition to analytical information, the Scheduler can provide data storage allowing permanent records to be stored. Information which could be stored includes date, time, and location of the data. Currently 240 separate analytical records can be stored before the memory is full.

There is one important technical limitation to the Scheduler in its current form. It will not operate properly if the physical temperature of the electronic components drop below $0^{o}C$. Techniques for keeping the Scheduler warm would need to be developed if it is to be used below $0^{o}C$.

I hope this answers some of your questions regarding the Scheduler. Let me know if I can be of any further assistance.

Sincerely,

Bronson Gardner

Bronson Gardner

BRG/bjl

RECEIVED
MAY 16 1988
S. C. DeSUTTER

STANDARD OIL
ENGINEERED MATERIALS

J. D. Dunn

5/13/88

TO: A.H. CLARK
L.F. KAHL

We have been discussing use of the Scheduler with Westlake.

Dave Dunn

jdd/sp
attachment

BCC: S.C. DeSutter

cc Bronson
Chuck

BP Ventures

RECEIVED

MAY 1 ? 1988

J. D. DUNN

Britannic House, Moor Lane, London EC2Y 9BU

Mr. K. Goode,
BP Energy Ltd.,
BP House,
53-57 Belmont Road,
Uxbridge,
Middlesex UB8 1QS.

Personal callers to:
Britannic House West,
Silk Street, EC2

CONFIDENTIAL

Our reference	Your reference	Telephone	Date
TEC/000/137/01		01-920 3262	3rd May 1988

Dear Mr. Goode,

I thought it would be useful to place on record our short telephone conversation on 28th April.

I am in touch, for several reasons, with two groups in BP who are co-operating on inspection and corrosion problems associated with lagged process plant pipelines. Deterioration of lagging and ingress of moisture can result in substantial costs (multi-million) due to corrosion which are made even worse by the need to strip off and replace lagging in order to carryout a visual inspection.

Currently these groups are investigating the use of infra red devices to measure heat flux from the lagged pipes in order to identify areas where the lagging has deteriorated and where the pipeline beneath may require inspection or treatment. Two instruments are known to be available. One of these is manufactured by the Engineered Materials Division of BP America ("EMCO") and will require a small modification from its existing specification. The other is available only as part of a service from a small private company based near Bonn. The latter is primarily involved in energy management and surveys of both buildings and process plant. It is of course possible that other instruments are available although initial enquiries suggest they are unlikely to be common and as a guide the EMCO device sells for $4200.

In the event that the observations and correlations observed in preliminary field trials are confirmed then it is possible that there could be an opportunity for either sale of suitable instruments or the supply of a regular survey service to a potentially large international customer base in which BP has an established reputation.

My reasons for contacting you were firstly find out if BP Energy already has experience with similar devices and secondly to see if BP Energy might wish to explore either of these opportunities as a possible new business area.

We agreed that the idea is probably worth investigating further and I have since asked Martin Underwood at the BP Research Centre to contact you once the equipment details are known. Information on the practical aspects of pipe lagging inspection can be obtained from Barry Johnson (ext 2305) or Mike Kinnear (ext 2917) in the Engineering and Technical Centre at West Britannic House.

Perhaps you would let me know if you take this any further.

Yours sincerely,

D.J. WESTLAKE
Licensing Business Development

c.t. J.D. Dunn, EMCO Niagra Falls
S.W.B. Lloyd, C/I BDU
D. Smith, VTR
P. Baikie, VTR
D. Chesneau, RBD
B.V. Johnson, ETS
D.M. Kinnear, ETS
File TEC/000/137/01

[redacted]

MR. L. KAHL

Not recommended.

with compliments

RECEIVED
JAN 9 1989
LUIZ F. KAHL

John Mitchell
Regional Co-ordinator
Western Hemisphere

3.1.89
The British Petroleum Company p.l.c.
Britannic House, Moor Lane, London EC2Y 9BU
Tel: 01-920 7981

[redacted]

CARBORUNDUM

Bonjour,

Please see the attached.

I have to respond to Dave.

1-22-12.

EVEREST INTERSCIENCE INC.
SURFACE THERMOMETRY

RECEIVED
JAN 16 1989
J. D. DUNN

December 8, 1988

Mr. John Mitchell
British Petroleum
Britannic House
Moor Lane
London EC2Y 9BO
England

Dear Mr. Mitchell:

The enclosed comparison of the Scheduler and The Yielder is another example of the manner in which SOHIO is trying to put Everest Interscience down by their false advertising. The Comparison was sent to us by our Australian representative.

My rebuttal, for your information, is enclosed also.

Sincerely,

Marilyn M. Everest

Marilyn M. Everest

Dave Dunn
o While I'm the boss I'll be the Bad guy
o When we're going to give it.
o Please

1120 S. Raymond, Fullerton, CA • 92631 • USA • P.O. Box 3640, Fullerton, CA 92634-3640 • USA
Telex 295368 • (800) 328-3677 • FAX (714) 992-0178 • (714) 992-4461

RESPONSE TO M. Everest letter dated Dec. 8, 1988
Field Testing/Design

The Scheduler became a commercial product in 1985, but obviously must have been tested/evaluated/developed prior to becomming a commercial product. It is true that the pre-production version used Everest infrared thermometers and that we continued to use Everest infrared thermometers through Feb. , 1986. This does not mean that the Scheduler design and product was understood by Everest, however. Several important features were developed during the 1984-1986 period which Everest may not be aware of :

. Solar radiation design. The criteria for an acceptable solar radiation sensor were established independent of Everest. Scheduler prototyping demonstrated the importance of simultaneous measurements of solar, air, crop , and humidity parameters.

. Theoretical calculations. The heart of the Scheduler is the equations which calculate our proprietary form of CWSI. The CWSI equation which we use is not identical to the IDSO equation which Everest uses in the Yielder. We believe the enhancements that have been made result in a better product. They also result in a better understanding of how the product should be used in practical situations.

. Ergonomic designs. Since 1984, we have been designing the features of the Scheduler. The 1985 instrument can be easily recognized in the prototype form that was used during 1984.

. University Testing. Major universities and leading USDA researchers across the country have participated directly in the testing of the Scheduler. We have also received direct input from many growers on field results. This activity began in 1984. We have worked with all the major CWSI researchers in the country, with the exception of those located in and around Phoenix and Tucson, Arizona. We avoided researchers in these locations because of their close commercial ties with Everest. In the process, we have helped train an entire new group of CWSI researchers. We have been directly responsible for establishing/starting/assisting CWSI research at 80-100 university and government sites. The Arizona researchers which we avoided have their principle expertise in cotton and wheat. Since we had reliable sources of information for these crops, there was no technical need to work with them. Our data-base from qualified university researchers is extremely large.

. Patent Process. The first discussions on filing for a patent were held in late 1984. We have never claimed that CWSI was patenable. We did identify/test hardware and software features which are the subject of patents. The fact that we used Everest sensors to assist in our tests and evaluation is a matter of record. Scheduler features extend well-beyond this one sensor.

. Vendor sources. Everest was only 1 of several infrared vendors which were evaluated for supplying infrared thermometers for the Scheduler. The company was selected because they offered the first non-mechanically chopped infrared thermometers which claimed to have the same specifications as a chopped infrared thermometer. This claim was found to be false, spurring the developement of our own non-mechanically chopped infrared thermometer, which does meet the specifications required for the Scheduler. Everest was not informed of the results/details of our field testing. Nor were any of the other vendors.

ENGINEERING

We are well aware of the fact that the USDA established the initial specifications for hand-held infrared thermometers for use in agriculture. The same experts which provided these specifications also strongly encouraged/asked Everest (and other infrared thermometer companies) to build a prototype instrument which could use the CWSI concept. These requests were made at least as early as 1982 (based on conversations with Mel Keener and Don Slack). It is likely that requests were made even before this. It is curious that Everest did not respond to these requests until after the Scheduler became a commercial product.

DISPLAY

We do not offer a "constant, real-time" display of CWSI, because it presents too much information to the average consumer. The only information which is of value to a user is the overall average. Displaying every CWSI calculation is a feature only a few researchers care about. The fact remains that our display screen is large and easy to read when compared to the Everest display screen, regardless of what information is being displayed. We can change the content of our display by simply changing our program. They cannot change their display screen size without changing their hardware design.

SAMPLING

While there may be "thousands " of Everest sensors on the market, there are very few "Yielder" instruments. The "Yielder" is the first Everest instrument I am aware of which requires the user to pull a trigger to store data. My comment still stands. I believe that someone who uses one of his devices as much as some of our Schedulers get used will dislike his trigger, especially if they have the opportunity to do a side-by side comparison. The fact remains that the Scheduler can store 240 separate data sample averages, which can represent between 240 and 240,000 individual samples. On intensive days, we have seen researchers fill a Scheduler memory twice (approximately 5000 individual samples). Any body who flexes their finger 5000 times in 1 day will probably know about it the next day. The "Yielder" can store 400 individual data samples.

INTERNAL CLOCK

If the "Yielder" had time and date functions when I examined it, then I missed it.

PACKAGE

The holster for the "Yielder" is also a recent addition. The first one I have seen displayed was at the Agronomy Show in November, 1988. Their advertising brochure simply indicates they have a "carrying case".

BASELINES

It is true that we have avoided working with the researchers who invented CWSI. This was done, since they were in constant and close communication with Everest about their work. It made no sense to provide a potential competitor with free information.

The broader issue of baselines is critical. The Scheduler baselines are based on a simple phiolosphy : if they can be proven to work, then they can be sold. If they cannot be proven to work, they they should not be sold. Some CWSI researchers believe that it is a simple matter of 2-3 days worth of work to establish a baseline line. Wrong. It takes an entire season to establish a possible baseline. It takes another season to independently test the baseline and make needed modifications. Simultanteous to the development of a baseline is the development of the economically important agricultural interpretations. Simple, generic curves do not help a farmer make important decisions. The baseline development procedure we use is :

a. collect Scheduler/agronomic data throughout a season on as many days as possible.

b. develop a preliminary baseline and agronomic interpretations based on these field results. We use major universities/researchers for this work.

c. establish independent irrigation scheduling trials in which the crop is irrigated solely on the basis of the Scheduler and compare with conventional techniques. We use major universities/researchers for this work.

d. refine the baseline and agronomic interpretation

e. commercially offer a baseline to the marketplace. We then have the requisite experience and knowledge to offer direct and meaningful advice to a grower.

f. collect data from selected growers to continue evaluating the baseline and refining the agronomic interpretations.

Feedback
The "Scheduler" has always had an audible feedback. Apparently,the "Yielder" now has audible tones. When the comparison article was written, the "Yielder" models being marketed did not have audible feedback. Marilyn Everest told me directly that they "had no plans" to put one in. I have not heard the tones that theirs emits, so I cannot compare them. The units they had on display in November, 1988, at the Agronomy show did not make any audible sounds. This addition must have been very recent.

INSTRUMENT WARM-UP

The Scheduler infrared thermometer does not use a mechanical chopper for stabilization, instead, it uses "digital chopping". This means that the Scheduler is smart enough to detect the fact that the sensor is unstable and can correct for the errors induced. Independent university test results and our own extensive calibration tests demonstrate the accuracy and reliability of our infrared thermometer. We have conducted "side by side" tests of Schedulers and Model Ag-42 infrared thermometers (Everest technology) and shown that under the same heating and cooling conditions that the two technologies perform virtually the same. The end-user will get a quality infrared thermometer in either instrument. The way we achieve this performance is a combination of superior mechanical/thermal design , quality construction and properitary calibration techniques. The reason we recommend long equilibration times is to insure that the air temperature and humidity sensors have sufficient time to adjust to ambient conditions. There is always the possiblity that the temperature of the housing an air temperature sensor is in can influence the readings. I have not seen any test results (nor been able to perform any tests myself) to demonstrate that a "Yielder" measures air temperature as accurately and quickly as an infrared thermometer can respond.

The fact is that Everest is the one who should prove that his air temperature sensor works. His previous "Delta-T" device (which measured air temperature) was evaluated by many researchers and found to be inaccurate.

INFRARD THERMOMETERS

It comes as no surprise that Everest can make a quality infrared thermometer.

Technical Support

I don't know what she means. She has told me many times that they are a "small mom and pop company" without the resources to conduct the type of research we can conduct. If Everest is developing a dealer network, this is something new.

PRODUCT AGE

The basic Scheduler design was established late 1984 and January, 1985. The first Scheduler units were produced months before the two Model 112's were purchased. No reverse engineering was used. The basic electronic design of an infrared thermometer is so simple that a freshman electronics student in college could design the circuit. The challenge comes in providing thermal stability (the Model 112's were not thermally (stable). We designed the Scheduler infrared thermometer without reverse engineering. There is so much more to the Scheduler than an infrared thermometer.

PRODUCT LEADERSHIP

Everest did sell a kit which consisted of his basic infrared thermometer, a small programmable calculator, and somebody else's humidity/air sensor device. It is true he received an award for this package. Awards don't mean a whole lot. What counts in leadership is who develops the marketplace and makes the sales. It is true the ASAE gave the "Yielder" an award in 1988. ASAE gave the "Scheduler" an award in 1987. We have also received an award from CAL-POLY, perhaps the best agricultural engineering school in the country. Our product is patented.

There was no genuine marketplace for infrared thermometers in agriculture until the Scheduler was marketed. Prior to that time, the almost exclusive agricultural marketplace was the Agronomy Society and the Agricultural Engineers. Scheduler representatives have educated literally thousands of growers, dissemenated many many newsreleases, attended uncounted trade shows, talked at many dozens grower meetings and have in general created a demand for this type of product.

Rebuttal to SOHIO's
Comparison and True Facts

FACTS

Field Testing	The Scheduler couldn't have been field tested since 1984. It has supposedly been a product since 1985. Also, as late as February of 1986, they were still buying the main sensor heads from Everest. Please see SOHIO's P.O. No. ST RJ 04366 dated 2-10-86.
Design	Everest has been in direct contact with the researchers responsible for developing the CWSI from the beginning. All work to develop the CWSI was done using Everest designed instruments.
Engineering	Initial specifications for the natural environment infrared thermometer were dictated by USDA researchers. Experts in agriculture, physics and from management gave input to the World's leading expert in infrared thermometry, Charles Everest, and his Computer Scientist, Gary Kostalnick, in the design of the Yielder.
Display	Constant, real-time display of the CWSI directly in the field is only offered on The Yielder.
Sampling	The Yielder instantaneously stores all parameters it reads at the touch of a finger. No one has complained of any "pain" while using an Everest Infrared Thermometer and there are thousands of sensors on the market.
Air/RH Design	The Yielder is aspirated, also. It, too, can tolerate the same heating/cooling effects.
Field Use	The comparison gives erroneous information. Everest, after years of field work, suggests that users follow the researchers habit of taking a number of measurements in the field from opposite directions. Not only are the temperature and humidity different from a truck, they can be different from the side of the field to the middle.
Feedback	The Yielder has an audible tone.

Instrument Warm-up	The Scheduler needs to be equilibrated in the field because it doesn't have the necessary temperature compensation and chopper stabilization that The Yielder has. This perfection has come from over twenty years of research and development by Charles Everest and his employees.
Internal Clock	Obviously, SOHIO didn't do its home-work. The Yielder has an internal clock.
Package	I can only say they "protest too much". Liken the Scheduler to the old fashioned video camera and heavy holder for the tape to The Yielder which is the new generation Camcorder. Again SOHIO, didn't do their homework. The Yielder comes with a holster. So, if it's free hands you need you got it. If it's accurate readings you want - you've got it with The Yielder.
Baselines	Obviously SOHIO doesn't know where the data on baselines have come from since they steer away from the researchers who developed them and claim to have invented them (see attached newsletter).
Infrared Thermometer	The Scheduler's performance may have been verified but this comparison fails to give any results. Yes, Everest has been developing precision infrared thermometers for decades. They are the leader in this field. However, The Yielder is a truly new and revolu-tionary design.
Technical Support	Again SOHIO doesn't know what they are talking about. Who is calling whom "lazy."

The Scheduler has been a product since 1985 because SOHIO purchased two of Everests Model 112's on July 25, 1985 on their P.O. No. 42-0227-E352-00 and reverse engineered them.

Charles Everest has been designing infrared thermometers for use in the natural environment since the late 70's and infrared thermometers in general for over 20 years.

If the Scheduler is "the clear leader in crop stress monitoring using infrared thermometry," please explain away the fact that Charles Everest received a prestigious international award "for the conception, design and implementation of a unique infrared thermometer for use by agronomists in optimizing irrigation scheduling and water usage" in 1984 by the Instrument Society of America!

This year the American Society of Agriculture Engineers has deemed The Yielder should receive The Top 50 AE Award at their meeting in December.

CARBORUNDUM

The Carborundum Company
Instrument Technologies
6180 Cochran Road
P.O. Box 391377
Solon, Ohio 44139

Telephone 216 349-6881
Telefax 216 349-6897

January 19, 1990

Mr. Luiz F. Kahl
The Carborundum Company
P. O. Box 156
Niagara Falls, NY 14302

Dear Mr. Kahl:

During my tenure with The Carborundum Company I have reflected many times on how fortunate I was to be allowed to work on the Scheduler^{R} Plant Stress Monitor. Before beginning a new project (at the Warrensville Lab), I wanted to express my appreciation and gratitude to you for being so patient with our efforts. Despite our lack of economic success, The Carborundum Company can feel proud of its development efforts and the instrument which resulted.

This project has always been fortunate to have excellent management. The necessity of discontinuing the Scheduler effort should in no way reflect on the performance of those who managed the project. The simple truth is that not enough American farmers are yet prepared to use advanced technology. The research community (USDA and many universities) are supportive. Research projects are underway to develop new applications for this instrument. In short, the Scheduler has been a solid technical success. The project was extremely well managed. The public just wasn't ready for it.

Again, thank you for taking the risk associated with this effort. I shall always appreciate it.

Sincerely,

Bronson Gardner

Bronson R. Gardner, Ph.D.
Product Technical Manager

BRG/lb

CARBORUNDUM

The Carborundum Company
Instrument Technologies
6180 Cochran Road
P.O. Box 391377
Solon, Ohio 44139

Telephone 216 349-6881
Telefax 216 349-6897

January 19, 1990

Mr. J. David Dunn
The Carborundum Company
P. O. Box 156
Niagara Falls, NY 14302

Dear Dave:

Just a note to say thank you for providing me the opportunity to work for you on the Scheduler^{R} Plant Stress Monitor project. The time I have spent with The Carborundum Company has brought many unique experiences and taught me some important lessons. Despite our lack of economic success, a truly good product was built.

Again, thank you for taking the risk. Good luck in the future in your other assignments.

Sincerely,

Bronson R. Gardner, Ph.D.
Product Technical Manager

BRG/lb

CARBORUNDUM

The Carborundum Company
Instrument Technologies
6180 Cochran Road
P.O. Box 391377
Solon, Ohio 44139

Telephone 216 349-6881
Telefax 216 349-6897

January 19, 1990

Mr. Steven C. DeSutter
The Carborundum Company
P. O. Box 156
Niagara Falls, NY 14302

Dear Steve:

Just a note to say that working for you has been enlightening in many ways. While the work was not always easy, and the pressure often high, I can honestly say that I enjoyed it. Thank you for the way in which you devoted yourself to the project and kept us focused on the task-at-hand.

Although the Scheduler^{R} Plant Stress Monitor was not an economic success, it was a technical success. I am pleased and proud of having been a part of the team effort.

Good luck in your new job. Again, thank you for providing leadership direction and friendship throughout the time we worked together.

Sincerely,

Bronson Gardner

Bronson R. Gardner, Ph.D.
Product Technical Manager

BRG/lb

Brenson

TRIP MEMO

TO: S. C. PRICE

FROM: M. E. KEENER

SUBJECT: ASAE WINTER MEETINGS

I attended the last two days (December 12-13) of the winter meetings of the American Society of Agricultural Engineers in New Orleans. The following are a synopsis of the papers I attended and the contacts made.

1. E. Stegman used canopy temperatures as a scheduling technique for corn. He used several methods including the Idso method. His irrigation criteria was 0.2 and 0.4 units of the Idso method. He achieved a 22% reduction in water use with a 5% yield loss using a value of 0.2. The 0.4 value resulted in a 16% yield reduction.

2. B. Belcher showed some results of using canopy temperature for irrigating soybeans in South Carolina. There were no hard results from this, however.

3. A. Kottwitz showed that historical averages of pan evaporation is better as a predictor of daily pan evaporation than are models based on Markov processes.

4. Met with Bruce Curry. Discussed the sensitivity analysis of his soybean model.

5. Talked to Dr. Dale Heermann, USDA-ARS, Fort Collins, Co. He is working farmers in Eastern Colorado and Oregon on irrigation scheduling. He seemed interested in testing a prototype of our irrigation scheduling device.

6. Was introduced to Dr. Julian Pitchford of Rainbird. He has a lot of experience in designing and placing irrigation equipment in foriegn markets. He also seems to have a lot of ideas that Rainbird is not taking advantage of. One such idea is to hook a varaible pumping rate irrigation pump to a solar panel. The advantage of this is to let the motor run as fast as the solar cell can supply the power with the idea that it is easier to store water than to store electricity. He has indicated that he is not completely satisfied with Rainbird.

ACTION TO BE TAKEN

1. This corresponds to our value of 0.3 as an selection criteria for scheduling irrigation.

2. Might be a contact for that area of the US for the irrigation scheduling project.

3. No Action.

4. Maintain contact to monitor progress on the grant.

5. D. Heermann could give us some contacts for possible farmer (consultants) contacts for this summer's irrigation scheduling work.

6. Maintain contact to see if this person can give us some help in the international market. It is also possible that this person could fill the same role as planned for Fred Heppler.

MEMO

To: S. C. Price
From: M. E. Keener and B. R. Gardner
Subject: Trip memo- Nebraska

Three days were spent at the Sandhills Agricultural Laboratory collecting photosynthesis, transpiration, and canopy temperature data on the x-corn plots. The weather for the first two days was very good. The data collection for the afternoon of the third day was interupted by intermittant cloud cover. All equipment performed well. The mass storage device current being used, a cassette recorder, is very slow in handling large amounts of data. The LICOR infrared analyzer is fairly stable and commercial grade CO2 can be used for calibration instead of the more expensive research grade. No more than three runs can be made in one day using two people. The major limiting factor is the portable photosynthesis system. It is our feeling that only one person should operate this so as to eliminate any operator variance.

RECOMMENDATIONS

1. A new method of mass data storage be explored-probally some type of floppy disk drive.

2. The data collection crew remain at two.

3. The site be revisited the first of August for additional measurements during the grain filling stage.

4. Before arrival at each site, have a cylinder of commercial grade CO2 delivered.

Bronson

To: S. C. Price
From: M. E. Keener
Subject: Trip memo-Arkansas

I worked with Brad Boyd of Benson Lake Farms, Inc. on the use of the infrared thermometer as an irrigation scheduling device. Three days of data were taken on corn that was about a week from tasseling. The irrigation system they use is a traveling gun. This gave the opportunity to look at parts of the field that had been irrigated at different times. From this data and that data Bronson collected (see the attached memo on his trip to Nebraska), we are convinced that the devices and the protocol that we have established can be sucessfully used for irrigation scheduling.

ACTION

1. Revisit both locations after pollen shed to take additional measurements to insure that the same protocol will work during the grain filling period.

2. It is probably too late in the growing season for a contractual arrangement with the Arkansas growth.

3. Begin work on a patent proposal for the device and the protocol.

4. Begin work on building a prototype for use next summer.

MEMO

To: S. C. Price
From: M. E. Keener
Subject: Trip memo-Missouri

The purpose of this trip was to visit the frost tolerance corn test and the x-corn trials in Clarence, Mo. The details are as follows.

1. There is no regrowth in the frost tolerant experiment.

2. The x-corn variety trial is about 2 weeks from tassel emergence. Data on stomatal resistance and canopy temperatures was taken. The interface between the autoporometer and the polycorder did not work very well. Several problems were experienced.

3. Allen Wright sucessfully defended his thesis. He will be leaving for South Africa to take a position in plant water relations of corn and wheat.

4. Selected the volunteer papers for the Symposium for the American Society of Agronomy. Some problems have surfaced in terms of people being able to make the meetings.

ACTION TO BE TAKEN

1. Recommend that the final report on the 1983-84 experiment at Clarence for the frost tolerant corn be requested and the land area be abandoned.

2. Analyze the data taken. Solve the problems in the interface between the polycorder and the autoporometer. Plan for another visit approximately 3 weeeks after pollen shed (mid-August) to take data on stomatal resistance, canopy temperatures, and net carbon exchange rates.

3. Maintain contact with Dr. Wright for the purpose of expanding the potential market for x-corn.

4. Finalize the schedule for the Symposium.

PROJECT LEADER RESPONSIBILITIES

To successfully implement the "project leadership" concept, each project leader must understand the importance of his/her responsibility. True progress cannot take place unless the project leader organizes, communicates, and implements project strategies consistent with the project objectives. The key characteristics of good project leadership will include:

- Effective travel scheduling.
- Establishing and meeting quantative weekly and monthly objectives.
- Clear, direct communications with project manager and project team members.
- Problem solving as the number one responsibility of the project leader (bring solutions to the table).
- Meeting planning and reporting deadlines.
- Obtaining approval at critical stages of strategic implementation.

PLANNING RESPONSIBILITIES

The project leader must develop a project plan that will include the critical aspects of success for each project within his region of responsibility. The project plan will identify the projects key objectives and those factors critical to meeting these objectives. It will include project strategies and key activities, as well as milestones (completion dates). This planning activity must be coordinated with the project manager to assure accurate project mission and objectives.

PROJECT PLAN COMPONENTS

Statement of Your Project's Major Objective(s): This should be contained in two paragraphs or less.

Current Project Status: This is an overview of the project to date and will vary in length depending on the project. Remember, state only the facts in bullet-point style communication if possible. This is not an exercise in literary skill.

Strategy: Clearly define your strategy to meet the major objective(s) of the project. Identify them in a step-by-step form and include key activities and dates on which you anticipate completion of each step.

Forecasting: Identify the quantity of product (sales volume, new applications communications activities, etc.) that will come from successful implementation of your plan. Include specifics that are measurable (i.e. dates and volumes).

REPORTING PROCEDURES

Project Plan: Rough drafts are due by September 7, 1988.

Completed Plan: Will be due on designated dates pending rough draft reviews.

Monthly Highlights: Are due by the 5th of the following month (not more than one page in length). Highlight performance against objectives.

Weekly Reporting: This reporting system will be designed to meet the specific project leader needs and will be developed with the project manager.

CHASE BRASS & COPPER COMPANY
6180 Cochran Road, P.O. Box 39548
Solon, Ohio 44139
216-349-0200

Bangerskis, Karlis, I.	6780	Holling, Charles, L.	6778	Randa, Marian A.	6808
Bayus, Joan M.	6713	Hurtig, Monika	6863	Randlett, M. Ronald	6760
Blair, David R.	6716	Jamieson, William L.	6783	Rostocil, Arthur J.	6864
Boros, William A.	6779	Kinsley, Robert L.	6717	Smiley, Ollie E.	6817
Bower, Terry F.	6757	Knight, William D.	6702	Snyder, Ronald H.	6714
Burchill, Monte L.	6711	Kocka, Donald E.	6719	Teresi, Barbara C.	6759
Cavanaugh, Charlene B.	6723	Lauge, Sigurds	6852	Tipping, James R.	6726
Cherney, Edward J.	6777	Legerski, Edward A.	6800	Tryby, Jill C.	6806
Conley, Barbara M.	6706	Lemp, David J.	6834	Tu, Jerry C.	6762
DiPasquale, Lawrence J.	6707	Lindsley, Deborah S.	6880	Tucker, William B.	6870
Disterhof, Lee A.	6802	Michalski, Stanley W.	6779	Unetich, Edward A.	6715
Gibbs, Sherry G.	6709	Millward, James R.	6730	Wright, Frank E.	6700
Gladyszewski, Clarence	6850	Petty, Samuel R.	6776		

STANDARD OIL MANUFACTURING SYSTEMS ENGINEERING

Bogucki, Sandy	6740	Hildebrand, Richard	6841	Ruhl, Robert C.	6747
Bona, Salvatore	6821	Mulac, Dennis	6899	Worner, Gary A.	6750
Eckert, Robert	6826	Poor, Kathy	6749	Wright, Jack	6752
Eucker, James L.	6799	Remeika, Thomas E.	6803		

STANDARD OIL METALLURGICAL

Cleary, John E.	6865	Conrad, Brian	6861	Hultgren, Frank A.	6860

STANDARD OIL ENGINEERED MATERIALS

Bucknell, Lynn	6881	Fiorina, Cherese	6889	Scholl, Chuck	6886
DeSutter, Steve	6882	Gardner, Bronson	6887	Sypen, Art	6890
Dew, Robert	6891	Riley, Korbin	6884		

STANDARD OIL ENGINEERED MATERIALS - INSTRUMENT TECHNOLOGIES

Carter, Robert	6842	Kodramaz, Rick	6846	Lingenfelter, Ruth	6896
Dalley, Raymond	6843	Kondos, John	6845	Wright, Brelinda	6895
Grant, Cherie	6898				

Analytical Lab	6774	First Aid	6789	Pilot Area	6781
Basement	6784	Lobby	6736	Pilot Area	6818
Computer Room	6773	Mail Room	6737	Receiving	6783
Computer Room	6838	Mechanical Test	6775	Weld Shop	6807
Electronics Lab	6776	Metallurgical Lab/SEM	6777		

Outside Line Access Code - 9

Solon Police Dept.	248-1234
Solon Fire Dept.	248-1212

Bucknell, Lynn (Bob)
5375 East 139 Street
Garfield Heights, OH 44125
663-7910

DeSutter, Steve (Nancy)
285 Chemsford Drive
Aurora, OH 44202
562-1015

Dew, Robert (Barbara)
27 Ennis Avenue
Bedford, OH 44146

Futey, Joe
5371 Regency Drive
Parma, OH 44129

Gardner, Bronson (Colleen)
13965 Milo Road
Garfield Heights, OH 44125
475-9568

Riley, Korbin (Vicky)
9124 Lake in the Woods Trail
Chagrin Falls, OH 44022
543-1840

Scholl, Chuck (Debby)
3156 Chadbourne Road
Shaker Heights, OH 44120
991-5954

Soroczak, Dennis (Judy)
5009 Stickney Avenue
Cleveland, OH 44144

Sypen, Arthur (Janet)
16265 Munn Road
Chagrin Falls, OH 44022
564-7031

Dalley, Raymond (Wendy)
10095 Pirates Trail
Aurora, OH 44202
562-6896

Grant, Cherie (Tim)
1624 State Rt. 303
Streetsboro, OH 44241
626-5411

Grensing, Rita (Fritz)
19432 Winslow
Shaker Heights, OH 44122
991-5670

Hayes, Bruce (Linda)
20705 Kenyon Drive
Maple Hts., OH 44137
475-6349

Kodramaz, Rick (Jackie)
400 E. 326th Street
Willowick, OH 44094
585-0406

Kondos, Jack (Stacy)
41 Olive Street
Chagrin Falls, OH 44022
247-7634

Lingenfelter, Ruth
628 Sill Avenue
Cuyahoga Falls, OH 44221
928-5331

Obert, Warren (Elaine)
310 Chatham Drive
Aurora, OH 44202
562-7588

Pagonis, Sandy
9404 Trivue Circle, Apt. D
Twinsburg, OH 44087
425-8289

Dunn, Dave (Joanie)
112 Fairview Court
Grand Island, NY 14072

TUBE DIVISION - Toll Free 800-458-8470
NARROW STRIP DIV. - Toll Free 800-228-7383

ROD DIVISION - Toll Free
In Ohio - 800-472-4581
Outside OH - 800-537-4291

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Knight, William D.	6702	Tu, Jerry C.	6762
Kocka, Donald E.	6719	Tucker, William B.	6870
Lauge, Sigurds	6852	Twiggs, Alan J.	6783
Legerski, Edward A.	6779	Unetich, Edward A.	6715
Lemp, David J.	6834	Wright, Frank E.	6700
Linsley, Deborah	6723		

THE CARBORUNDUM CO. - INSTRUMENT TECHNOLOGIES

Bucknell, Lynn P.	6881	Lingenfelter, Ruth M.	6896
Dalley, Ray J.	6843	Obert, Warren H.	6842
Gardner, Bronson A.	6887	Paganini, Raymond J.	6889
Grensing, Rita A.	6895	Pagonis, Sandra C.	6847
Hayes, Bruce J.	6804	Scholl, Chuck T.	6886
Kodramaz, Rick A.	6846		

BP AMERICA - HERMETIC CAPACITOR GROUP

Boczek, Michael	6764	Zeigler, Keith A.	6764
Lab	6764	Zeigler, Todd A.	6764

Analytical Lab.....6780	Dave Lemp(Pager)..574-5239	Metallurgical Lab 6777
Basement.....6784	Our FAX No.....349-4047	Pilot Area.....6781
Computer Room.....6838	Electronics Lab.....6776	Pilot Area.....6818
Computer Room(Engr.)..6872	First Aid.....6789	Receiving.....6783
Dock Area.....6773	Lobby.....6736	Tube Line.....6818
BP America (HQ)...586-4141	Mail Room.....6737	Weld Shop.....6807
Alan Twiggs(Pager)766-2234	Mechanical Test.....6775	

Solon Police 248-1234 Solon Fire Dept. 248-1212

Night Service Access Code is 4
System Speed Dialing has been programmed for the following numbers:

CODE	TELEPHONE NUMBER	
#100	(9) 586-4141	Standard Oil - Cleveland
#101	(9) 261-4800	Sheet Division
#102	(9) 1-419-485-3193	Rod Division
#103	(9) 1-704-482-8200	Narrow Strip Division
#104	(9) 248-1234	Solon Police Department
#105	(9) 248-1212	Solon Fire Department
#106	(9) 349-2273	St. Luke's Emergency
#107	(9) 361-1050	Honeywell
#108	(9) 749-6400	Meridian Travel
#109	(9) 781-8714	Piedmont Airlines